NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

ENERGY RESILIENCY FOR MARINE CORPS LOGISTICS BASE PRODUCTION PLANT BARSTOW

December 2014

By: Christopher J. Czumak and
J. Christian Woodside

Advisors: Nicholas Dew
Philip Candreva

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2014	**3. REPORT TYPE AND DATES COVERED** MBA Professional Report		
4. TITLE AND SUBTITLE ENERGY RESILIENCY FOR MARINE CORPS LOGISTICS BASE PRODUCTION PLANT BARSTOW				**5. FUNDING NUMBERS**
6. AUTHOR(S) Christopher J. Czumak and J. Christian Woodside				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) Marine Corps Logistics Command Installation and Logistics Command Headquarters Marine Corps				**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N/A____.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited				**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The purpose of this thesis is to examine feasible microgrid and on-site energy generation options to provide power infrastructure resiliency aboard Production Plant Barstow (PPB), such that the site has suitable standalone power to endure emergency or catastrophic situations. The main objective is to analyze the best options available to create resiliency for continued PPB depot maintenance functions during temporary or catastrophic natural or adversarial disruptions to its power infrastructure.

First, we collect and normalize energy and environmental data specific to PPB and Barstow, CA. Second, we analyze the cost and suitability of renewable and alternative energy sources, and microgrid technology. Last, we determined the value of PPB's energy security and create energy portfolio options based on various sensitivity analyses. The result is an analysis framework for achieving resiliency at PPB and additional Marine Corps Logistics Command (MCLC) production plants.

This study provides an analysis of PPB's Value of Electrical Energy Security (VEES), offers recommendations for selecting a cost-effective, resilient and scalable alternative energy portfolio, and creates a levelized cost for a microgrid and its components by combining data from various credible sources in order to fully understand appropriate investment criteria. Additionally, it provides feasible energy options that are aligned reduce PPB's greenhouse emissions, dependencies on limited resources, increase energy efficiency and use of Renewable Energy (RE) and Alternative Fuel, and create energy security in accordance with Department of Defense (DoD) mandates and the Marine Corps stated objectives for its installation energy strategy. This analysis will assist the Marine Corps to determine specific actions to create energy resiliency programs at PPB and future sites.

14. SUBJECT TERMS Renewable Energy, Energy Security, Marine Corps Installations, Value of Energy Security, Modern Portfolio Theory, Solar, Photovoltaic, Wind, Biomass, Waste-to-energy, Energy Planning, Energy Strategy, Value of Electrical Energy Security, Customer Damage Function, Cost of Interruption, and Probability of Interruption.			**15. NUMBER OF PAGES** 95
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

ENERGY RESILIENCY FOR MARINE CORPS LOGISTICS BASE PRODUCTION PLANT BARSTOW

Christopher J. Czumak
Captain, United States Marine Corps
B.S., Auburn University

J. Christian Woodside
Lieutenant, United States Navy
B.A., George Washington University

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2014

Authors: Christopher J. Czumak
J. Christian Woodside

Approved by: Dr. Nicholas Dew
Thesis Advisor

Phillip Candreva, Senior Lecturer
Second Reader

William R. Gates, Dean
Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

ENERGY RESILIENCY FOR MARINE CORPS LOGISTICS BASE PRODUCTION PLANT BARSTOW

ABSTRACT

The purpose of this thesis is to examine feasible microgrid and on-site energy generation options to provide power infrastructure resiliency aboard Production Plant Barstow (PPB), such that the site has suitable standalone power to endure emergency or catastrophic situations. The main objective is to analyze the best options available to create resiliency for continued PPB depot maintenance functions during temporary or catastrophic natural or adversarial disruptions to its power infrastructure.

First, we collect and normalize energy and environmental data specific to PPB and Barstow, CA. Second, we analyze the cost and suitability of renewable and alternative energy sources, and microgrid technology. Last, we determined the value of PPB's energy security and create energy portfolio options based on various sensitivity analyses. The result is an analysis framework for achieving resiliency at PPB and additional Marine Corps Logistics Command (MCLC) production plants.

This study provides an analysis of PPB's Value of Electrical Energy Security, offers recommendations for selecting a cost-effective, resilient and scalable alternative energy portfolio, and creates a levelized cost for a microgrid and its components by combining data from various credible sources in order to fully understand appropriate investment criteria. Additionally, it provides feasible energy options that are aligned reduce PPB's greenhouse emissions, dependencies on limited resources, increase energy efficiency and use of Renewable Energy and Alternative Fuel, and create energy security in accordance with Department of Defense mandates and the Marine Corps stated objectives for its installation energy strategy. This analysis will assist the Marine Corps to determine specific actions to create energy resiliency programs at PPB and future sites.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

BTU	British Thermal Units
CDF	Customer Damage Function
CEC	California Energy Commission
COG	Cost of Generation
CSI	California Solar Initiative
DoD	Department of Defense
$/kW	Dollar per Kilowatt
$/kWh	Dollar per Kilowatt Hour
$/mWh	Dollar per Megawatt Hour
ETV	Environmental Technology Verification Program
ESTCP	Environmental Security Technology Certification Program
FY	Fiscal Year
HQMC	Headquarters, United States Marine Corps
IAW	In Accordance With
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelized Cost of Energy
MCLB	Marine Corps Logistics Base
MCLC	Marine Corps Logistics Command
MMBTU	Million British Thermal Units
MT	Microturbine
mW	Megawatt
mWh	Megawatt Hour
NG	Natural Gas
NPV	Net Present Value
NREL	National Renewable Energy Laboratory

OMB	Office of Management and Budget
PPA	Power Purchase Agreement
PPB	Production Plant Barstow
PV	Photovoltaic
RE	Renewable Energy
SAIDI	System Average Interruption Duration Index
SAIFI	system average interruption frequency index
SERDP	Strategic Environmental Research and Development Program
VEES	Value of Electrical Energy Security

EXECUTIVE SUMMARY

In April 2014, we were commissioned to conduct a study on improving energy security for Production Plant Barstow (PPB), Marine Corps Logistics Base Barstow, Barstow, CA. Our task is to examine feasible microgrid and on-site energy generation options to provide power infrastructure resiliency aboard Production Plant Barstow, such that the site has suitable standalone power to endure emergency or catastrophic situations. Given that on-site power generation systems used to increase energy security also have an environmental benefit, our study offers alternatives that assist the Marine Corps in reaching its targets of reducing installation energy consumption by thirty percent and increasing installation renewable energy consumption by fifty percent by 2020. Therefore, as a means to meet the needs of our stakeholders and comply with the energy directives set forth by the Commandant of the Marine Corps, we've aligned the research and analysis in this study to create a clean, efficient, resilient, cost effective and secure energy solution for Production Plant Barstow that integrates alternative and Renewable Energy resources. This analysis will assist the Marine Corps to determine specific actions to create energy resiliency programs at Production Plant Barstow and future sites

Energy resources in Barstow are abundant, however, only two of the alternative or renewable energy systems researched provide a cost-effective power generation solution for Production Plant Barstow. We selected photovoltaic and microturbines as the two technologies for further data analysis, as they offer the lowest Levelized Cost of Energy, smallest geographical footprint, and high environmental benefits for use. Although natural gas used in microturbines is subject to the volatility of global markets, the historical price of natural gas has remained stable and predictable over time.

As indicated by solar and wind projects at the Nebo and Yermo Annexes, Marine Corps Logistics Base Barstow has made a substantial effort to diversify its energy portfolio. However, adding power generation sources is only half the battle of achieving energy security. Microgrids are necessary for power distribution to critical infrastructure, and currently one of Marine Corps Logistics Base Barstow's most important tenants is bound to an electrical grid that can be defined as unpredictable. Therefore microgrids are

another important component to achieving energy security, and function as a proactive means to transition to islanding activities while ensuring operational stability.

Figure 1 shows four separate microgrid architectures, each distinguished by different generation resources and utility grid integration. Types 1b and 2b incorporate renewable energy generation, and the 2b architecture has the potential to island itself completely from the utility grid. Within the 2b architecture there are two subsets:

1. Low Penetration Photovoltaic (PV) with backup generators, grid interactive, and
2. High Penetration PV with backup generators, grid interactive (Van Broekhoven, Judson, Nguyen, Ross, 2012)

Due to fluctuations in solar radiance, the recommended microgrid architecture is based on the Type 2b High penetration photovoltaic design and integrates microturbines and batteries, with units for power distribution, load balancing, control and intentional islanding.

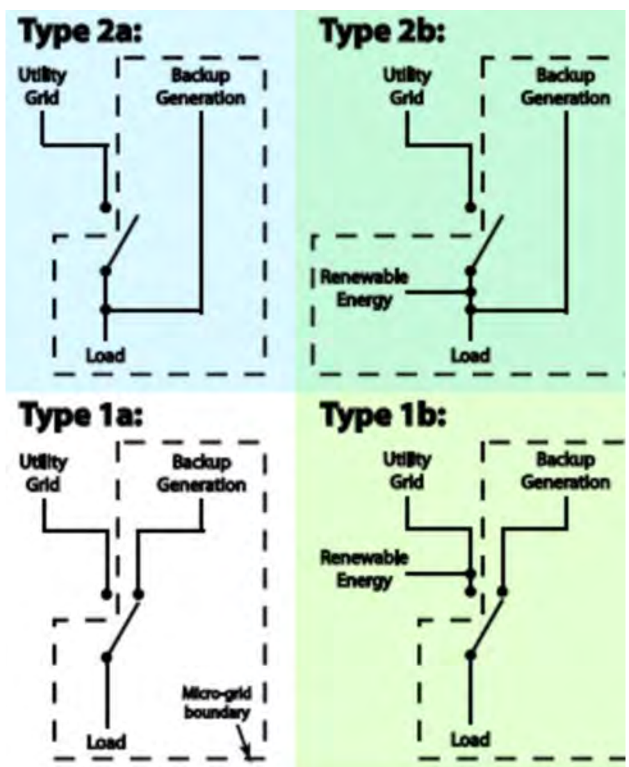

Figure 1. Types of Microgrids

Valuing security is made possible by capturing energy information and using the Valuing Electrical Energy Security (VEES) framework to determine costs associated with temporary and sustained interruptions, and to calculate the cost savings achieved by installing a resilient energy system (Giraldez, Booth, Anderson, Massey, 2012). By applying the Value for Electrical Energy Security we can better understand the costs of interruption associated with underinvesting in energy security and use it as a metric for mitigating future risk. Additionally, we can use VEES as a way to justify spending for our critical infrastructure. Figure 2 shows the total VEES Net Present Value (NPV) savings per year, over a twenty year period, as a means to depict the potential cost savings achieved by investing in energy security. More information on calculating the VEES is provided on page 6 and in the methodology chapter of this study.

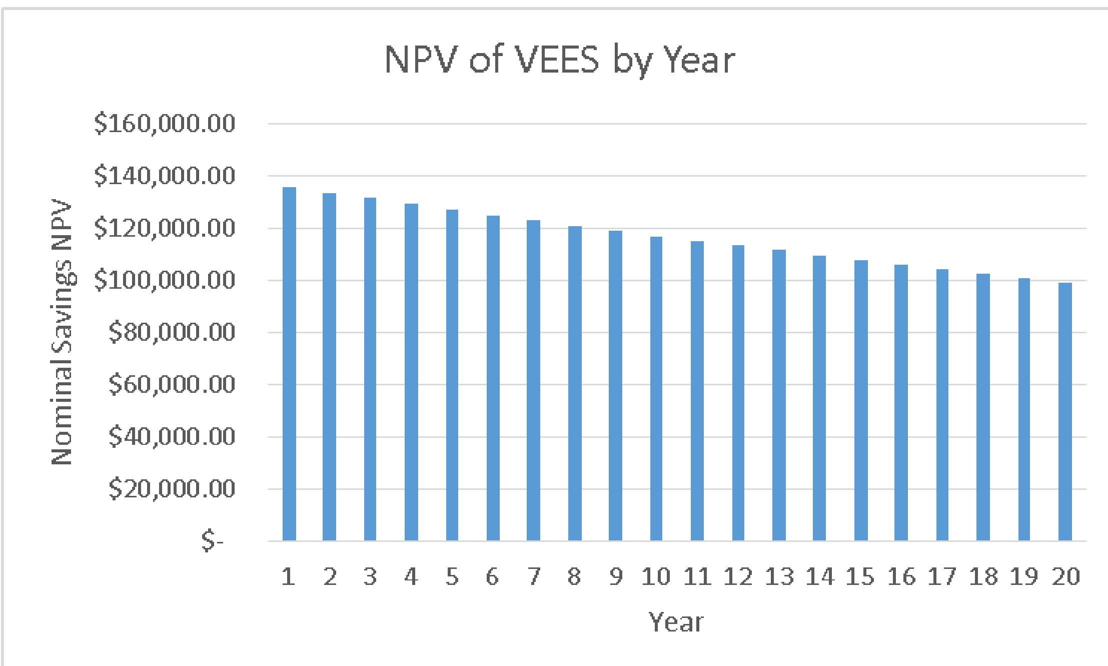

Figure 2. VEES Net Present Value Savings Per Year

The derivatives of investing in the microgrid technology outlined in this study aren't just an increase in reliability or reduction in cost, there is also strong evidence of environmental benefits in comparison to traditional power generation methods, all of which neatly aligns with policies and mandates set forth by the Marine Corps. At its

current utility baseline electricity usage, Production Plant Barstow greenhouse emissions total 1070.59 metric tons per year. Assuming that a 3.5MW photovoltaic array generates approximately forty-six percent of Production Plant Barstow's electricity over a period of twenty years, this translates to a reduction of 5816.58 metric tons in emissions per year on average. If coupled with microturbines, another 2613.25 metric tons of greenhouse gasses can be eliminated per year on average, understanding that emissions reductions may vary based on the generation source of utility grid power. Therefore we can assume that any future investment that Production Plant Barstow makes in microgrid technology assists the Marine Corps in reaching its targets of reducing installation energy consumption by thirty percent and increasing installation renewable energy consumption by fifty percent by 2020.

Figure 3 shows the potential reduction in gas emissions per year, for a twenty year period, if PPB decides to install the microgrid architecture recommended in this study.

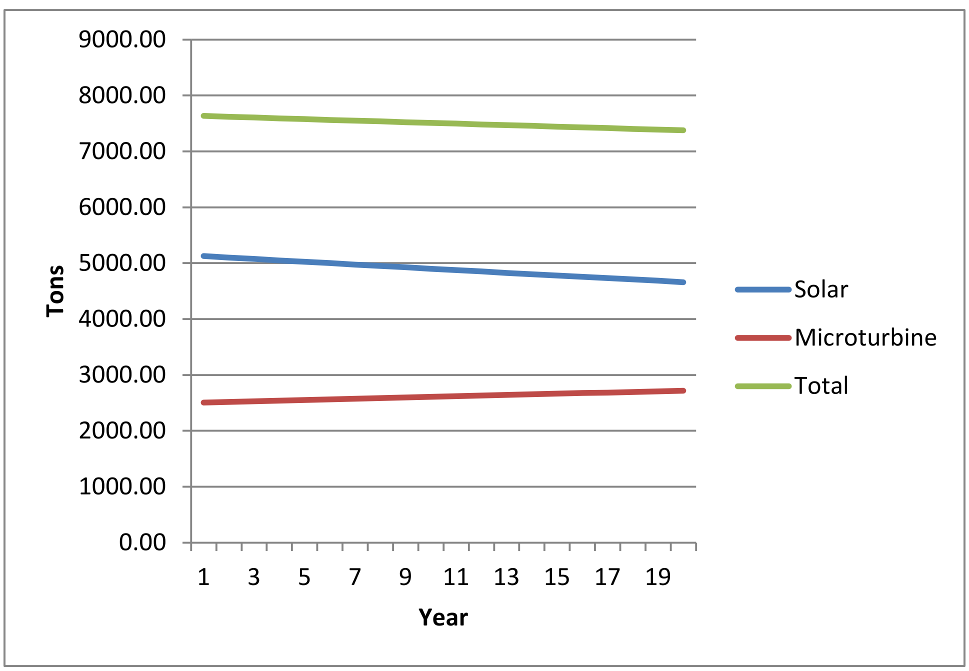

Figure 3. Reduction in Gas Emissions per Year

In our analysis we determined the levelized cost of energy for different power generation sources over twenty years and found a positive NPV savings. The NPV

includes all associated cost such as operations and maintenance, capital install cost, natural gas cost, and microgrid install cost. In all cases onsite generation proposals have a positive NPV over the status quo, purchasing power from a commercial utility. Further analysis of the Value of Electrical Energy Security adds additional savings to the analysis. By installing a type 2B microgrid, Production Plant Barstow will decrease the frequency of power interruptions through a diverse generation portfolio. This decrease in interruption is calculated by applying the VEES formula per year through a twenty year analysis. We found the NPV of the VEES and applied it to the NPV from new energy generation to find a total NPV of savings over the 20 year period.

Figure 4 shows the net present value of a twenty year savings, including the VEES, achieved by investing in different energy security portfolios. Each architecture assumes the installation of a Type 2b microgrid architecture.

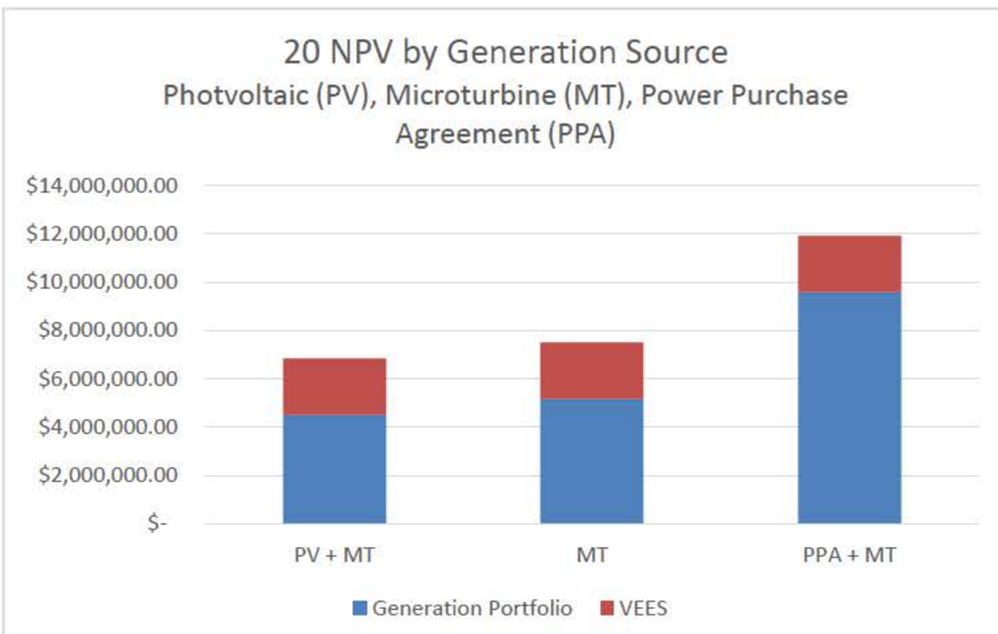

Figure 4. Twenty Year Savings by Generation Source

LIST OF REFERENCES

Giraldez, J., Booth, S., Anderson, K., & Massey, K. (2012). Valuing energy security: Customer damage function methodology and case studies at DoD installations (No. NREL/TP-7A30–55913). Golden, CO: National Renewable Energy Laboratory.

Van Broekhoven, S. B. Judson, N. Nguyen, S. V. T. Ross, W. D. (18 June 2012). “Microgrid Study: Energy Security for DoD Installations”, (ESC-EN-HA-TR-2012-103). Lexington, Massachusetts: Massachusetts Institute of Technology.

ACKNOWLEDGMENTS

We would like to thank our families and friends for their continued support during this educational milestone. We finally made it.

At Marine Corps Logistics Command, Logistics Capability Center, we would like to thank Huntley Bodden for the guidance and patience you offered us. At Marine Corps Logistics Command Barstow, we would like to thank Mr. Paul Florez and Mr. Tony Mesa for their critical energy-related inputs. At Marine Corps Logistics Command, Production Plant Barstow, we would like to thank Mrs. Alicia Florez and Mr. John Peterson for hosting us and creating a detailed picture of the inner workings of Production Plant Barstow.

To our second reader, Mr. Philip Candreva, we would like to extend our thanks for your editing expertise and professional inputs.

Last, we would like to covey our sincere appreciation for our professor and thesis advisor, Dr. Nicholas Dew for your professionalism, dedication and knowledge. Your hard work will have an everlasting impact on us.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE

Production Plant Barstow's (PBB) task to repair, rebuild, and modify Marine Corps ground combat, combat support and combat service support equipment makes it a critical component of the Marine Corps Logistics Command mission and the overall readiness of the USMC. The plant's reliance on external sources of energy decreases its security and resistance to electrical disruption, affects the readiness of MCLC and the Marine Corps, and therefore incurs a burden of cost in the form of time and money on the U.S. tax payer.

The purpose of this thesis is to examine feasible microgrid and on-site energy generation options to provide power infrastructure resiliency aboard Production Plant Barstow, such that the site has suitable standalone power to endure emergency or catastrophic situations. The main objective is to analyze the best options available to create resiliency for continued PPB depot maintenance functions during temporary or catastrophic natural or adversarial disruptions to its power infrastructure.

First we collect and normalize energy and environmental data specific to PPB and Barstow, CA. Second, we analyze the cost and suitability of renewable and alternative energy sources, and microgrid technology. Last we determined the value of PPB's energy security and create energy portfolio options based on various sensitivity analyses. The result is an analysis framework for achieving resiliency at PPB and additional MCLC production plants.

This study provides an analysis of PPB's Value of Electrical Energy Security, offers recommendations for selecting a cost-effective, resilient and scalable alternative energy portfolio, and creates a levelized cost for a microgrid and its components by combining data from various credible sources in order to fully understand appropriate investment criteria. Additionally it provides feasible energy options that are aligned reduce PPB's greenhouse emissions, dependencies on limited resources, increase energy efficiency and use of Renewable Energy (RE) and Alternative Fuel, and create energy

security in accordance with Department of Defense (DoD) mandates and the Marine Corps stated objectives for its installation energy strategy.

B. RESEARCH OBJECTIVES

Our research objectives:

1. Provide an overview of the Marine Corps Installation Energy Strategy,
2. Define energy resiliency,
3. Provide an overview of PPB's current energy usage and renewable energy initiatives,
4. Provide an overview of geographically suitable renewable and/or resilient energy solutions to include, wind, photovoltaic, microturbines, and their respective lifecycle costs,
5. Provide an overview of microgrid technology and the concept of islanding,
6. Determine if renewable energy and microgrid technologies are a credible investment aboard PPB, if the investment is cost-effective and resilient, has a positive Net Present Value, and to provide supporting justification and feasibility,
7. Determine if other on-site and off-site technologies are a credible investment to achieve energy resiliency, has a positive NPV, and to provide supporting justification and feasibility,
8. Provide a basis for comparing and selecting energy resiliency projects for PPB and other Marine Corps Logistics Command production plants.

C. RESEARCH QUESTIONS

1. Can our analysis assist PPB to increase its energy resiliency and align with the Marine Corps Installation Energy Strategy? This question addresses research objectives 1 through 7,
2. What are the energy and resiliency needs of PPB?
3. What are the energy options and lifecycle costs to meet the energy and resiliency needs of PPB?

D. SCOPE

In this thesis we identify feasible options to improve power infrastructure resiliency aboard PPB, in order to create redundancy and improve resiliency to withstand emergency or catastrophic situations. Through cost-benefit analysis we provide a framework for comparing and contrasting the costs and benefits for installing an energy resiliency project, in order to allow the stakeholder to make informed decisions in accordance with DoD and Marine Corps policy, and also based on the prevention of power disruption and to support security needs. Within this paper, we examine the current energy infrastructure of PPB in order to determine the minimum energy requirements of the plant at normal operating capacity and to assist in determining the value of energy security. To support our findings and to assist in a determination, this thesis examines regional data on renewable energy resource generation potential for PPB, renewable energy technology maturity and current lifecycle costs, and current on-site and off-site space available for future energy resiliency projects. The Mission Essential Tasks, as defined by the stakeholder, represent 100% of the plant's daily energy consumption, which is a determining factor for system installation and lifecycle costs.

E. STUDY BENEFITS

Current energy initiatives for tenant commands under MCLC are independent ventures, for which funding is submitted and approved on a case-by-case basis. As one of three major logistics production plants servicing the United States Marine Corps, it's imperative that a thorough analysis of resilient energy solutions is conducted for PPB, to ensure that future projects aboard PPB and other MCLC tenant commands are functional, cost effective and secure. Furthermore, these initiatives are aligned with the United States Marine Corps Installations Energy Strategy (Headquarters Marie Corps (HQMC), 2013), which outlines the Corps' shift toward improved energy planning and increased RE generation. This thesis provides a framework for PPB and MCLC tenant commands to assist it in its energy project planning by offering a comprehensive analysis of geographically available renewable and resilient energy solutions and their respective lifecycle costs, to include environmental and opportunity costs for land. In our efforts, we

examine the cost trade-offs of installing RE and microgrid projects, the project NPV, and the added security benefits.

F. METHODOLOGY

Our method for completing this study was by dividing it into two parts: (1) Reviewing current and past Marine Corps energy projects, assessing Barstow's potential for renewable and alternative energy and determining the environmental applicability of technologies, and measuring PPB's current state of energy security and supporting data. (2) Valuing PPB's energy security, and analyzing renewable energy project lifecycle costs and the benefits derived thereof.

In order to collect data for the first part of this study we researched Marine Corps installation energy initiatives that were either in the Southern California area or conducted by the Marine Corps Logistics Command. We researched energy initiatives in Southern California because of the environmental and pecuniary similarities to Barstow, and researched projects associated with MCLC because of the relevancy and availability of data from recent energy projects, which we know are familiar to our stakeholders. We collected data about Barstow's potential for renewable and alternative energy through the National Renewable Energy Laboratory (NREL) and independent energy vendors. We measured PPB's current state of energy security through energy consumption data and project information collected from Southern California Edison and the Marine Corps Logistics Base (MCLB) Barstow energy department, as well as from the Facilities Engineer during an on-site survey at PPB. Additional energy data used in this report was acquired from the U.S. Department of Energy and the U.S. Energy Information Administration.

Once we determined that we had enough data to meet the needs of our research objectives, we transitioned to the second part of our study, our analysis. First, we normalized all energy data by converting it to kilowatt (kW) per hour (kW/h) or Million British Thermal Units (MMBTU). Second, we valued PPB's energy security by creating a dollar per kW ($/kW) aggregate to measure the cost of power disruption and inputted it into the VEES formula for a total value of energy security, and then determined the Net

Present Value (NPV) over twenty year period. Third, we determined the twenty year NPV of the levelized cost of energy for each system type by combining installation, Operations and Maintenance (O&M), fuel, utilization rates, and equipment disposal data. Fourth, we determined the twenty year NPV of each system combined with a Type 2B microgrid architecture. Fifth, we used PPB's current electricity demand as a baseline and determined the twenty year NPV of different utility gird, renewable and alternative energy portfolios. Last, we created a twenty year environmental impact evaluation by applying the respective yearly emissions output to the projected power output of each system, and compared it to the emissions output of purchasing utility power from SCE. Note that all NPV calculations we use the standard NPV formula as described on page thirty-five of this study.

G. ORGANIZATION

This is a six chapter study. The first chapter is an executive summary that outlines our major findings. The second chapter is our introduction, which provides the study's purpose, research objectives and questions, scope, study benefits and methodology. The third chapter is our literature review that provides insight to the purpose of the study, information about PPB, defines energy security and the Marine Corps installation energy strategy and explores alternative and renewable energy sources in Barstow. The fourth chapter is the methodology of our study, or the roadmap of how we processed our data. The fifth chapter is our data analysis and cost-benefit analysis of feasible energy sources, as well as a full cost snapshot of a resilient energy system for PPB. In our last chapter we offer a conclusion to the study and recommendations for further research.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LITERATURE REVIEW

A. INTRODUCTION

This literature review provides insight into the data that we collected and utilized for the purposes of determining potential renewable and alternative energy resources at PPB. It includes information regarding the Marine Corps' stance on energy security and the future of energy security in the Marine Corps, it defines how we measure the value of energy security, explains the levelized cost of energy, explores PPB's current state of energy security, examines the applicability of RE technologies in Barstow, CA and offers insight into power purchase agreements and microgrid technology.

B. ENERGY SECURITY

1. The Marine Corps Installation Energy Strategy

In 2013, The Commander of Marine Corps Installation Command, Major General Kessler, approved the *United States Marine Corps Installations Energy Strategy* that outlines the Marine Corps plan to "unify and coordinate [The Marine Corps] approach toward energy" and to continue "improving readiness and mission support through the efficient use of energy and enhanced energy security on all Marine Corps installations" (HQMC, 2013). Of the five lines of operation outlined in the strategy, our study focuses on the following three: Energy Efficiency, Renewable Energy (RE) and Alternative Fuel, and Energy Security (HQMC, 2013). The other two lines of operation, Energy Ethos and Energy Information, are logically characteristic to our research.

Major General Kessler's publication provides refined guidance for installations originally published in the Commandant's *United States Marine Corps Expeditionary Energy Strategy and Implementation Policy*. In his energy strategy, the Commandant identifies three installation energy goals: First, certify that the energy provided to support operations and housing at Marine Corps installations is safe, reliable, and affordable. Second, reduce the overall lifecycle costs and hedge against market volatility, and third, support the national effort of conserving limited natural resources, increase energy security, and lessen the environmental impact of operations (HQMC, 2011). This study

also supports the quantitative objectives of reducing installation energy consumption by thirty percent and increasing installation RE consumption by fifty percent by 2020 (HQMC, 2011).

2. Energy security defined

Due to the unpredictability of an aging national power grid system, volatility in fossil fuels prices, growing concerns about the vulnerability of the U.S. electrical grid to attack, and the increased availability of independent energy generation resources via private vendors, the responsibility of producing and delivering reliable energy has begun to transfer to the stakeholder (Energy.gov, 2014). Therefore it is vital for DoD establishments to view energy security as a component of force protection.

Lincoln Laboratories defines energy security as "the ability of an installation to access reliable supplies of electricity and fuel and the means to use them to protect and deliver sufficient energy to meet critical operations during an extended outage of the local electric grid." (Broekhoven, Judson, Nguyen, Ross, 2012). We used this definition as a baseline for our technical research, but discovered during problem analysis that it did not fully meet the needs of our stakeholders. Due to the critical nature of PPB's mission, its contribution to the overall readiness of the USMC, and the historical financial and security impacts that occur as a result of temporary circuit disruptions on the utility grid, the stakeholders of this study expanded the definition of energy security as "resiliency to extended and *temporary* disruptions to its power infrastructure."

3. Value of Energy Security defined

The Value of Electrical Energy Security (VEES) framework was created to study the cost of power disruptions at DoD installations (Giraldez, et. al., 2012). The VEES framework is comprised of three components: (1) the Customer Damage Function (CDF), or "the value in dollar per kilowatts ($/kW) peak of an outage cost obtained from the CDF curve for a specified duration of the interruption" (Giraldez, Booth, Anderson, Massey, 2012). For this study we used the total $/kW of PPB workforce indirect and direct labor wasted during sustained power interruptions at PPB, (2) the peak site load, or the maximum amount of power used by PPB at a given time, and (3) the annual number

of outages, or the reliability of the power infrastructure at PPB. When the components are used together as an equation, the output is the annual cost of power disruption for a given site. (Giraldez, Booth, Anderson, Massey, 2012). In summary, the VEES is considered a crucial metric in this study for determining cost savings achieved by creating energy resiliency and it provides clarity to our stakeholders on the reliability of their power infrastructure.

4. Summary

Energy security is an essential component of mission readiness at DoD installations. As a means better understand the energy security needs of our stakeholders and comply with the energy directives set forth by the Commandant of the Marine Corps, we've aligned our research to support efficiency, resiliency, and environmental responsibility. Valuing security is made possible by capturing energy information and using the VEES framework to determine costs associated with temporary and sustained interruptions, and to calculate the cost savings achieved by installing a resilient energy system.

C. THE LEVELIZED COST OF ENERGY

The Levelized Cost of Energy (LCOE) is a comparison of energy generating technologies and their respective competitiveness within the energy production domain. The LCOE of a particular technology is the $/kW cost of its installation and operation which includes a combination of O&M, fuel, utilization rates, and in some analysis, financing (US Energy Information Administration, 2014). To ensure a more accurate estimate of the cost of a resilient energy system for PPB, we used the CA LCOE rather than the national median. Lazard states that in some comparisons between alternative and conventional technologies, the social and environmental externalities, as well as system resiliency measures, are not factored into the LCOE (Lazard, 2014). Depending on the technical composition of the energy portfolio that our stakeholders choose, a California Environmental Impact Report (CEIR) may be required by law prior to installing a power generation system. The fee for the CEIR is incumbent on the stakeholder and will therefore raise the LCOE of a particular technology. Additionally, the cost of system

resiliency measures, such as microgrid technology and islanding capability, is included in this study as required by the stakeholder.

The LCOE remains sensitive to the fluctuation in fuel prices, although alternative energy production is less sensitive to fuel prices than conventional methods (Lazard, 2014). The LCOE is also affected by state and federal subsidies which can cause a substantial decrease in the cost per mWh. Figure 1 shows the unsubsidized cost of the LCOE of alternative and conventional technologies and Figure 2 shows the sensitivity to subsidies of the LCOE of alternative and conventional technologies.

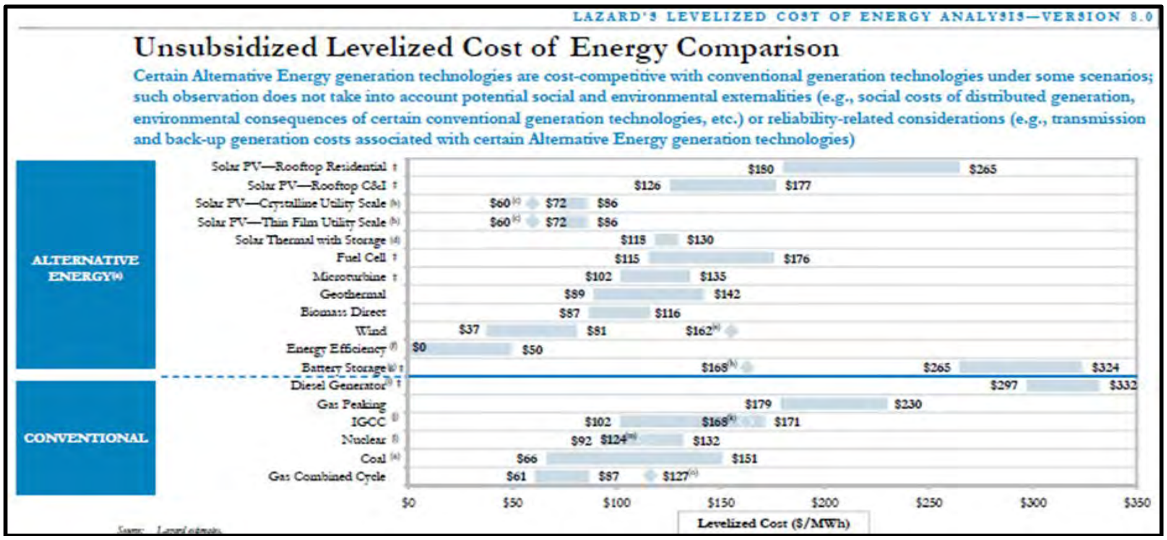

Figure 1. Lazard's Unsubsidized LCOE Comparison

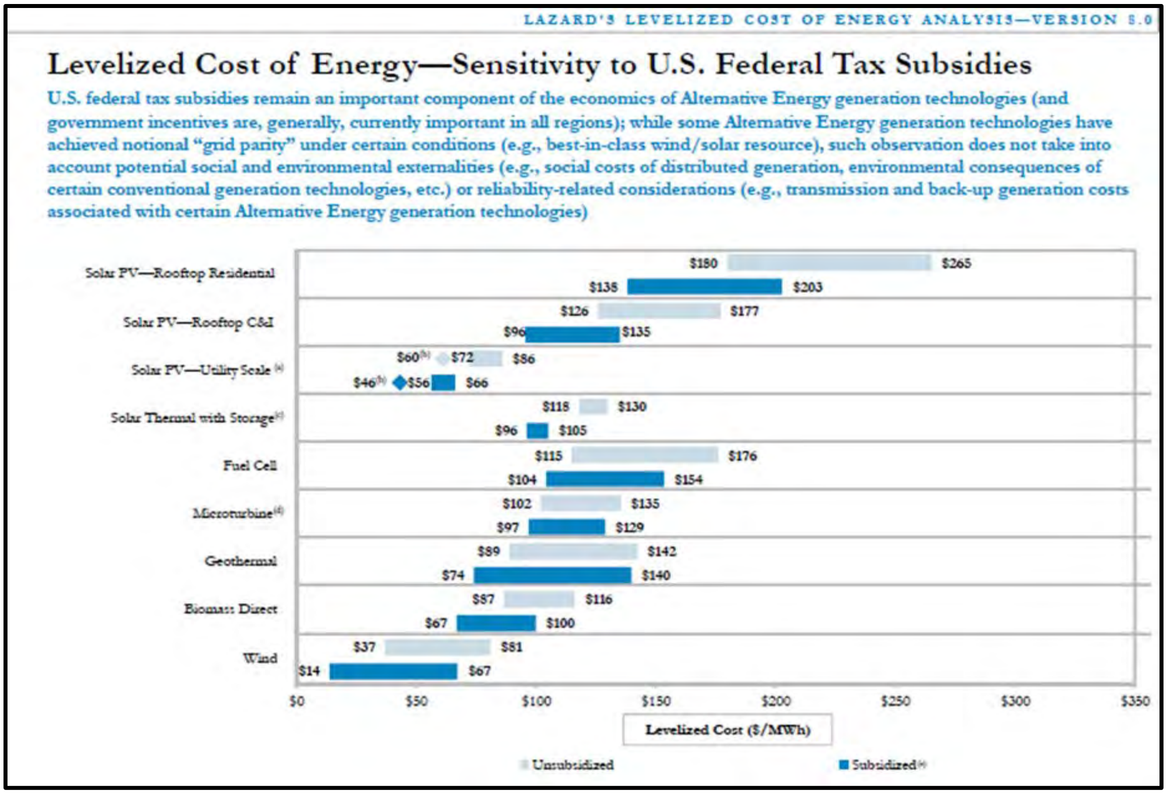

Figure 2. Lazard's LCOE – Sensitivity to Federal Tax Incentives

D. PRODUCTION PLANT BARSTOW

1. Overview

MCLB Barstow is located in Barstow, CA in San Bernardino County, approximately 36 miles southwest of Fort Irwin, CA and 99 miles northwest of Twentynine Palms, CA. The base is divided into two main areas, the Nebo Annex located on Interstate 40 and the Yermo Annex located 5 miles east of Yermo and south of Interstate 15. Production Plant Barstow is positioned aboard the Yermo Annex, and includes approximately twenty-four separately electrical metered buildings.

Barstow's average summer high temperature is 97 Degrees Fahrenheit (˚F) with averages peaking in the month of July at 101˚F. Barstow's average summer low temperature is 66.25 ˚F with averages dropping to 62 ˚F in the month of September. The average winter high temperature is 62.25 ˚F with average lows occurring in the month of January at 35 ˚F. The winter average low temperature is 37.75 ˚F (U.S. Climate Data,

2014). High and low outdoor air temperatures affect the efficiency of power generation equipment referred to in this study, and their impact will be explored in the methodology chapter.

2. Annual Electrical Cost

Southern California Edison provides electrical power to MCLB Barstow, with one primary electrical line running to the Yermo Annex. Electrical units are measured in dollar per kilowatt hour ($/kWh) or dollar per megawatt hour ($/mWh) at a conversion rate of

$$1 \text{ kilowatt hour (kWh)} = \text{megwatt hour (mWh)}\ x\ 1000$$

In January of Fiscal Year 2014 (FY14) SCE decreased the $/kWh by 10 percent, from $.1395 to $.1263. In FY14 PPB used approximately 15,515.819 MW of electricity, with a peak site load of 3.5 MW occurring in the month of August at a combined rate cost of $1,988,226.48.

3. Barstow Circuit Reliability

In order to determine the annual number and length of outages for inclusion in the VEES calculation, we needed to obtain power interruption and circuit reliability data from PPB's utility provider, Southern California Edison. SCE uses two primary metrics for determining circuit reliability in their service area: the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). The SAIDI is equal to the total minutes every customer is without power due to sustained outages divided by the total number of customers. The SAIFI is equal to the number of sustained outages experienced by all SCE customers divided by the total number of customers. The SAIDI and SAIFI rankings are numbered 1-36 with the number 1 representing the district with the lowest performance (Southern California Edison, 2014). The SAIDI and SAIFI chart shown in Figure 3 gives a snapshot of how long and how often PPB is without power each year, and offers a circuit reliability comparison between Barstow and other districts. We can assume that because the annual number of interruptions is included in the VEES formula, the higher the yearly SAIDI and SAIFI, the greater the cost incurred by our stakeholders.

Using data provided by SCE from 2008-2013, the Barstow district had an average SAIDI of 229.593 minutes of sustained outage time per year and an average SAIDI ranking of 10.166. Barstow had an average SAIFI of 1.531 sustained outages per year and an average SAIFI ranking of 10. Both rankings place Barstow in the top one-third of districts with the poorest circuit reliability, adding justification for an investment in energy security.

Reliability by District

	2008				2009				2010			
District Name	District SAIDI	SAIDI RANKING	District SAIFI	SAIFI Ranking	District SAIDI	SAIDI RANKING	District SAIFI	SAIFI Ranking	District SAIDI	SAIDI RANKING	District SAIFI	SAIFI Ranking
ANTELOPE VALLEY	92.18	22	0.96	20	71.23	29	0.52	33	131.06	17	0.77	31
ARROWHEAD	1239.36	1	5.43	2	534.08	2	3.41	1	537.40	4	3.84	2
BARSTOW	403.16	7	2.36	8	153.49	10	1.14	14	123.02	23	1.51	11

	2011				2012				2013			
District Name	District SAIDI	SAIDI RANKING	District SAIFI	SAIFI Ranking	District SAIDI	SAIDI RANKING	District SAIFI	SAIFI Ranking	District SAIDI	SAIDI RANKING	District SAIFI	SAIFI Ranking
ANTELOPE VALLEY	208.16	11	1.25	13	78.60	28	0.56	31	94.42	22	0.62	31
ARROWHEAD	792.79	3	4.40	1	129.58	13	1.31	7	180.59	7	1.39	8
BARSTOW	308.76	8	1.63	8	184.80	7	1.15	12	204.33	6	1.40	7

Figure 3. SCE SAIDI and SIAIF data 2008 – 2014

E. ENERGY SOURCES

1. Biomass, Landfill Gas, and Biogas

Biomass and Biogas availability is significant to this study because biogas is used at other Marine Corps Logistics Bases as a means of producing energy, and as an alternative to utility-provided electricity. However, Biogas has limited availability in Barstow due to the arid climate and is therefore not a feasible option for PPB.

2. Solar Energy

Average solar resources in Barstow range from 6.22 to 6.78 kWh/m²/Day, making solar an excellent energy alternative (National Resource Energy Laboratory, 2008). The left side of Figure 4 shows the photovoltaic solar resources across the United States.

MCLB Barstow has several solar energy initiatives in place, including a 772 kW array at the Yermo annex that distributes power directly to MCLB Barstow and operates under a Power Purchase Agreement (PPA). For the purposes of this study we assumed that land mass in or around the Yermo Annex can be used to support the installation of an additional solar array.

The cost of solar technology is trending downward as improvements in efficiency and increased incentives have caused the technology to reach grid parity in certain geographical locations. In 2012-2013, the national average cost of solar installation decreased by 12-15% from the year prior, which results in a dollar per watt decrease of \$.65 to \$.70 (Feldman, Barbose, Margolis, James, Weaver, Darghouth, Fu, Davidson, Booth, and Wiser, 2014). The total system cost for 2013 is modeled to be \$4.26/W for commercial systems in California >100kW, which is expected to decrease according to current estimates, as shown on the right side of Figure 4, Photovoltaic Installed Cost. Therefore, \$4.26/W is the cost of Photovoltaic (PV) install selected in this study.

3. Environmental Benefits

The EPA states that .000069 metric tons of CO_2 are emitted for the generation of one kWh of electricity by traditional technology. For this study, we can assume the reduction in CO_2 emissions for a PV array is equal to the total kWh size of the array multiplied by .000069 (EPA Clean Energy Calculator).

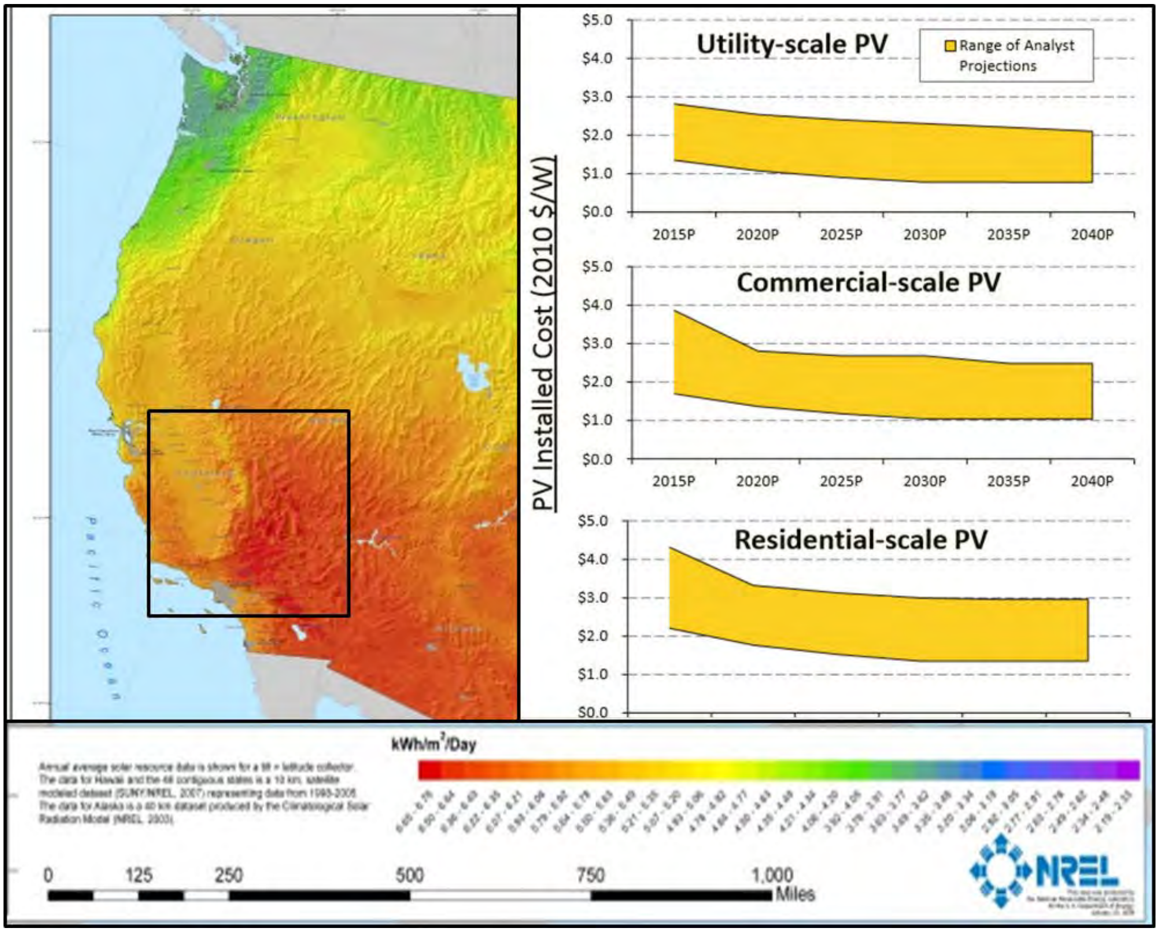

Figure 4. PV Installed Cost and Solar Irradiance in California

4. Wind Energy

As shown in Figure 5, wind power classification ranges from marginal to excellent in Barstow, making wind turbines a practical solution for renewable and independent energy generation. MCLB Barstow uses a 1.5mW wind turbine to generate energy for the Nebo area annex as part of their renewable energy (RE) initiative and in accordance with DoD mandates. The wind turbine was installed in 2009 with support from Southern California Edison and generates >3,000mW hours of power each year, reducing annual electricity costs by approximately $500,000 (Assembly Committee on Utilities and Commerce, 2014). The previous net energy metering interconnect arrangement stated that MCLB Barstow must operate the wind turbine under 1mW, limiting the amount of renewable energy produced by the turbine (Assembly Committee

on Utilities and Commerce, 2014). On 28 April, 2014 the Assembly Committee on Utilities and Commerce submitted a bill to increase the co-metering capacity to 1.5mW for the MCLB (which was opposed by the Southern California Public Power Authority) and enacted it into law in June 2014.

In addition to net-metering constraints, the DoD has recently opposed private wind projects in the Barstow area, due to concerns of radar disruption at local training and testing facilities (Vestel, 2014). Combined with a higher Levelized Cost of Energy and the large geographic footprints of wind turbines and associated equipment, wind-based energy production is not recommended for PPB.

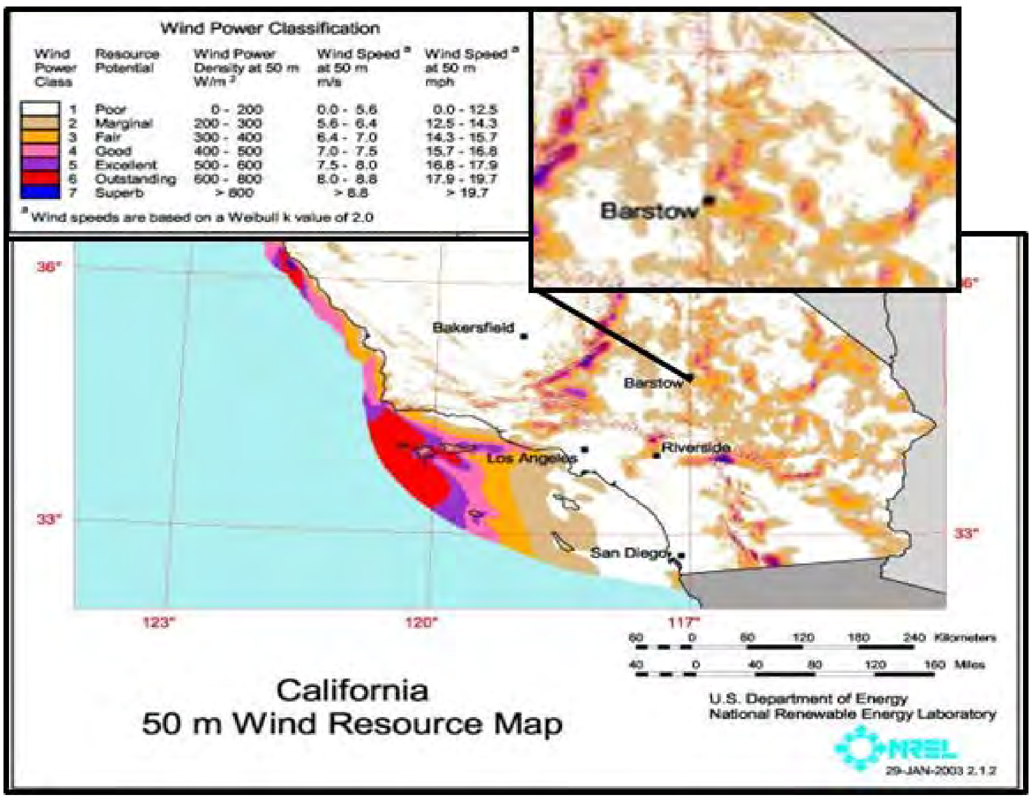

Figure 5. Wind Resources in Barstow

5. California Natural Gas Prices

The California Energy Commission (CEC) states that natural gas for local energy production is acquired from California gas pipelines that are tied to a regional system,

therefore gas prices are influenced by national trends. The CEC measures the Cost of Generation (COG) for gas-based energy production in nominal dollars per 1 million British thermal units (MMBTU) and uses historical data from the North American Gas-Trade Model, as well as other variables to predict future natural gas prices (California Energy Commission, 2014).. Figure 6 shows the high, mid and low-cost cases for California natural gas prices between 2013 and 2030, with the mid-cost price increasing by approximately 88% by 2030 (California Energy Commission, 2014). Natural gas price projections are relevant to this case for the LCOE and NPV of micro turbine systems, which are a feasible resilient power system.

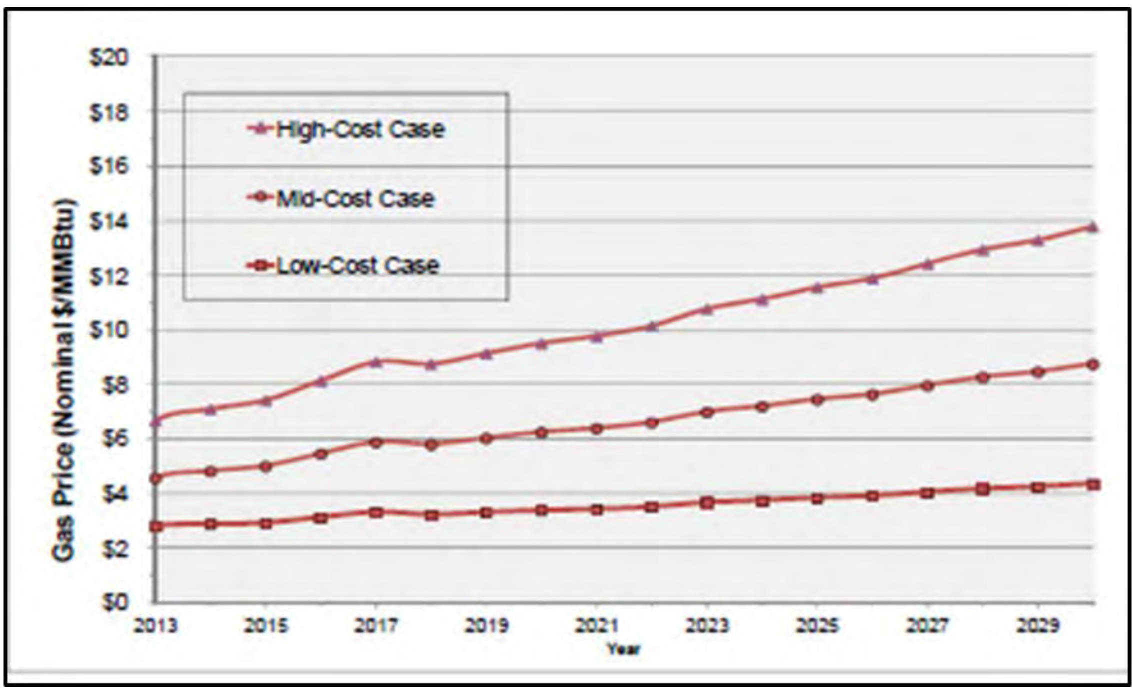

Figure 6. Gas Prices in MMBTUs 2013-2030

6. Microturbines

From 1995 to 2014 The Environmental Protection Agency (EPA) participated in the Environmental Technology Verification (ETV) Program. As a public-private partnership between the EPA and assorted nonprofit organizations, the program's focus was to verify the performance of developing environmental technologies (EPA, 2014).

During the program's tenure, the ETV verified the performance of several Microturbine (MT) technologies and the data was made public on the ETV website.

Microturbines are combustion turbines that use a compressor, combustion system, turbine alternator, generator and optional recuperator to generate electricity and heat from fuel (National Institute of Building Sciences, 2014). Modern commercial systems generally have a single moving part and can be used in a standalone or modular configuration to generate electricity ranging from 28kW to 1000kW (Capstone, 2014). With wind speed ratings of 155mph, operating temperatures from -4 to 122° F, and acoustic emissions at operation producing 65dBA, microturbines are a practical option for PPB (Capstone, 2014). In comparison to other alternative power generating technology such as wind turbines and PV, microturbines use less land area per MW (Capstone, 2010) and can be installed in approximately 90 days (Lazard, 2014, National Research Energy Laboratory, 2014).The Capstone Microturbine Corporation, a leading microturbine manufacturer, produces units ranging from 30 x 60 x 70 in (28kW) to 96 x 360 x 114 in (1000 kw) in size (Capstone, 2014). Microturbines can operate on a variety of gaseous and liquid fuels, including Natural Gas (NG), propane, landfill gas, digester gas, aviation, diesel, and kerosene, which give them useful flexibility in case of supply disruption of any particular fuel source. The microturbines also have optional gas compression accessories for added performance. For the purpose of this study we will be focusing on ETV verified microturbines that use NG for power generation, due to previously installed NG infrastructure at PPB, reduced emissions, and the cost savings associated with NG.

Microturbines are currently in use across the United States, with notable projects located at Syracuse University in Syracuse, NY and the Sheboygan Wastewater treatment plant in Sheboygan, Wisconsin (Capstone, 2014).

In a study conducted by the EPA, microturbine systems were found to reduce emissions of carbon dioxide, methane, and other environmental pollutants when used with clean burning fuels in place of traditional power generation systems. The EPA observed that ETV microturbine systems operating at 13mW reduced emissions of up to 36,120 tons per year of greenhouse gasses (U.S. Environmental Protection Agency,

2014). If scaled to a size of 3.5mW (the peak site load of PPB) and operating at full capacity, the installation of a microturbine system can translate to a reduction of 9692.3 tons of greenhouse gasses per year in comparison to traditional power generation systems.

Battery

Figure 7 shows the expected and target cost of lithium ion battery (A123 Presentation by Andy Chu, MIT Lincoln Laboratory, 2011). As noted, the current cost is \$500–\$700/kWh, and it is expected to reduce to \$400–\$500/kWh within the next few years – as the automotive industry increasingly purchases more batteries for plug-in electric and hybrid electric vehicles, the price is expected to fall due to economies of scale. In this analysis, the battery cost is assumed to be \$650/kWh. As discussed in the A123 Presentation by Andy Chu, MIT Lincoln Laboratory, it is not a practical option to use batteries as a main source of energy during an islanding event due to their high cost of investment. However, batteries do have practical application for short-term back-up solutions to support the transition to islanding activities, such as moderating voltage fluctuations. Therefore, we've included the costs of 15 minutes worth of battery back-up as part of a microgrid installation.

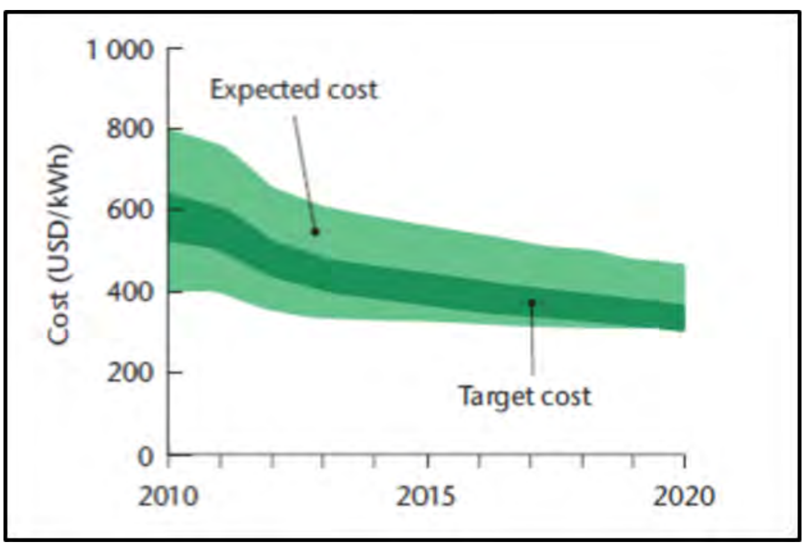

Figure 7. Future Battery Cost per kWh

7. Summary

Energy resources in Barstow are abundant, however, only two of the alternative or renewable energy systems researched provide a cost-effective power generation solution for PPB. PV and microturbines are the two technologies selected for further data analysis in chapter 4, as they offer the lowest Levelized Cost of Energy, smallest geographical footprint, and high environmental benefits for use. Although NG used in microturbines is subject to the volatility of global markets, the historical price of U.S. domestic NG has remained stable and predictable over time. Batteries are be explored as a resource to prevent intermittent fluctuations during grid transitioning.

F. COST FACTORS OF RENEWABLE AND ALTERNATIVE ENERGY SOURCES

The cost factors of renewable and alternative energy sources are important because of the effect that they have on the LCOE and NPV of a particular technology. The two cost factors described in this section, Power Purchase Agreement (PPA) and state and federal incentives, can dramatically lower the costs of installation and operation of RE and alternative energy.

1. Power Purchase Agreement

NREL describes a Power Purchase Agreement (PPA) as a "third-party ownership model, which requires a separate, taxable entity ("system owner") to procure, install, and operate [a] system on a consumer's premises (i.e., the government agency)" where "the government agency enters into a long-term contract to purchase 100% of the electricity generated by the system from the system owner" National Renewable Energy Laboratory, 2009). The system owner generates revenue from the sale of electricity to the consumer and additional savings are recognized by tax incentives offered to the owner by the federal government (National Renewable Energy Laboratory, 2009). There are benefits for DoD installations entering into a PPA, much of which is derived from using a third party owner to leverage technologies that offer tax-incentives (such as the 30% federal tax incentive on PV through the end of 2016, or state of California tax incentives on fuel

cells). Additionally, there are no up-front capital costs by the consumer for the installation of the equipment (Figure 8).

In this study PPA's are an assumed to receive incentives for PV, microturbine and microgrid projects and are included as a metric in our cost analysis of PPB's energy resiliency system project.

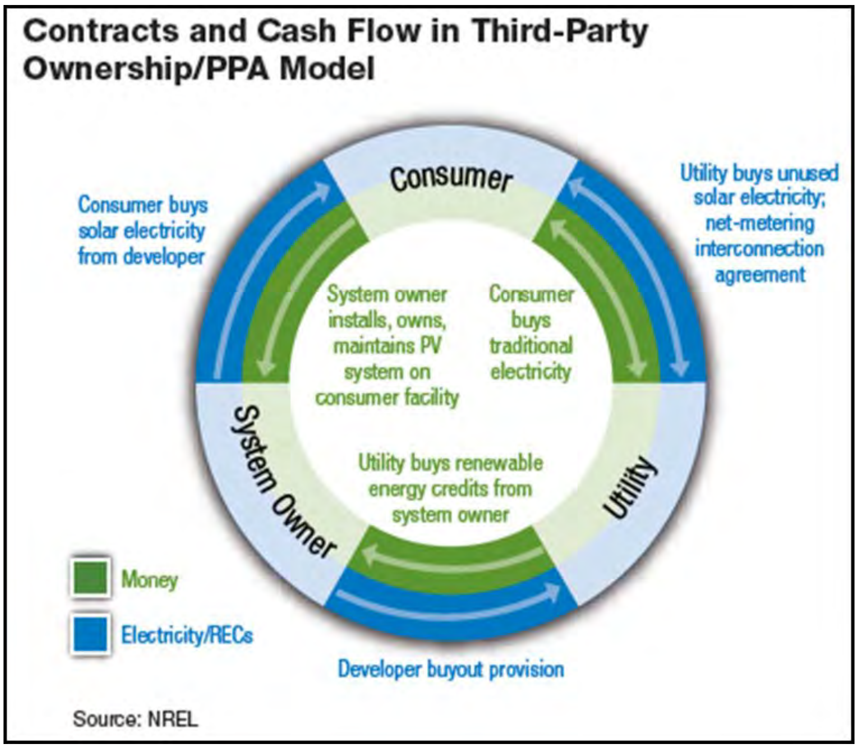

Figure 8. PPA Model

2. State and Federal Incentives

There are several state and federal incentives available for renewable and alternative energy projects. The Database for State Incentives for Renewable Efficiencies (DSIRE) maintains a database of such incentives located at DESIREUSA.org. The applicable incentives for this study are included in the cost analysis in chapter 4. Additionally, the sensitivity of energy technology to subsidies is discussed in the Levelized Cost of Energy.

G. MICROGRIDS

The Department of Defense defines a DoD installation microgrid as, "an integrated energy system consisting of interconnected loads and energy resources which, as an integrated system, can island from the local utility grid and function as a stand-alone system." (Van Broekhoven, Judson, Nguyen, Ross, 2012) The DoD definition of microgrids is exclusively used in this study as a means to examine the functionality and feasibility of a microgrid for added resiliency aboard PPB, and the reader should note that there are conflicting definitions of the term "microgrid" in various literature cited in the review. The use of the DoD definition is important because it includes the objective of linking a microgrid into the local utility grid, while adding the capability of "islanding" the site for which it is installed.

Lincoln Laboratory conducted a study in June of 2012 to analyze microgrids across DoD installations. Through surveys of over 50 installations, Lincoln categorized their findings based on size, maturity, inclusion of renewable resources, and ability to operate in a grid-tied manner. Based on the outputs of the study, Lincoln determined that there are four main types of microgrids in use at DoD installations; Type 1a (stand-alone backup generation), Type 1b (stand-alone generation with grid-tied RE generation), Type 2a (grid-tied backup generation that can be islanded), and Type 2b (grid-tied backup generation with islandable RE generation) (Figure 9) (Van Broekhoven, Judson, Nguyen, Ross, 2012).

1. Security Benefits of Microgrids

Microgrids are a force multiplier of energy security. Traditionally, uninterruptable power supply units and back-up generators act as an electrical stopgap for critical systems during power interruptions, however the need for responsive generator mechanics, the constant replenishment of price-sensitive fuels and physically dispersed assets makes traditional back-up power architectures a reactive contrivance. In contrast, microgrids function in a proactive manner by interconnecting critical infrastructure to a reliable and

redundant electrical source for power distribution and load balancing via a smart controller, with limited interaction from on-site technicians.

The Berkley National Laboratory states that the benefits of microgrids can be split into two main categories: local and broader benefits. Local benefits stem from a microgrid's positive contribution to a facility's operation, while broader benefits are the qualitative yield of positive externalities. Berkley asserts that local benefits include the increased reliability of power, greater efficiency, the integration of renewable energy, and use of on-site generation technology during normal operation – all leading to an increased cost savings. (Morris, Abbey, Joos, Marnay, 2011).

2. Microgrid Architectures

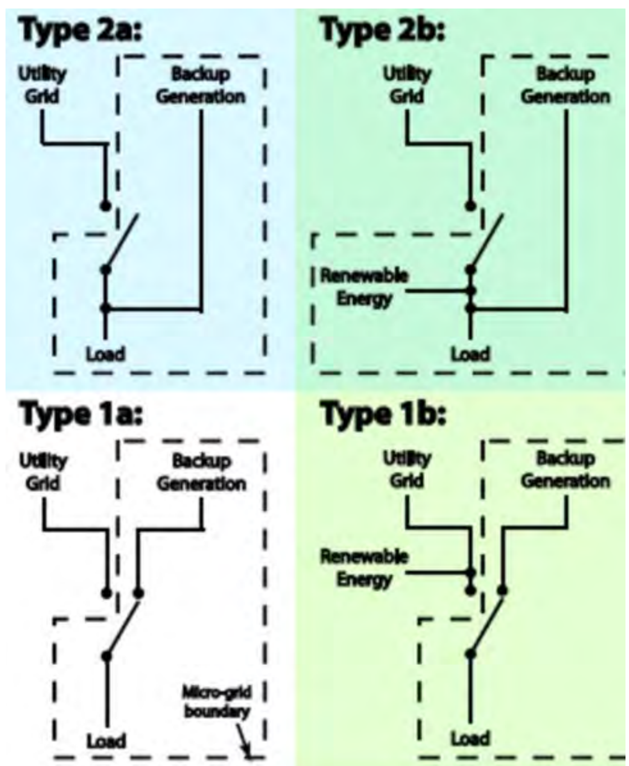

Figure 9. Types of Microgrids

Figure 9 shows four separate microgrid architectures. Different generation resources and utility grid integration distinguish the four architectures. Only the 1b and 2b designs

incorporate renewable energy generation and of the two only 2b has the potential to island itself completely from the utility grid. For these reasons this study will solely concentrate on 2b microgrid architectures. Within 2b architectures there are two subsets, Low Penetration PV with backup generators, grid interactive, and High Penetration PV with backup generators, grid interactive (Van Broekhoven, Judson, Nguyen, Ross, 2012).

The Type 2b Low Penetration PV architecture is similar to the 2a architecture but adds renewable generation to the portfolio of power generation resources. If PV generation is not sufficient to meet hourly power demands, then additional generators, such as microturbines, can be installed to bridge the gap in demand. Generator fuel would be the only source of energy storage on the 2b model with the exception of a small battery store. The low PV generation model assumes PV provides 25% of needed power generation (Van Broekhoven, Judson, Nguyen, Ross, 2012).

The Type 2b High penetration PV architecture uses both backup generators and PV, grid interactive, with batteries and is similar to the Type 2b Low PV architecture; however High Penetration PV can reach up to 75% of power demand. Due to the higher level of solar PV penetration in this architecture, a bank of batteries that can store 15 minutes of the maximum output from the PV system is installed to smooth out any short scale electricity fluctuations associated with transitioning activities (Van Broekhoven, Judson, Nguyen, Ross, 2012). The battery energy storage addresses two issues: (1) to provide stability by helping absorb short-term fluctuation in supply and demand and (2) to reduce the cycling of the generators, thus prolonging their lifetime. (Van Broekhoven, Judson, Nguyen, Ross, 2012).

3. Islanding

Islanding is the concept that the microgrid can completely disconnect itself for the commercial provider using its own power generation to provide electricity to the installation. When designing a microgrid with solar PV it must be designed with the most difficult islanding conditions in mind. Solar PV intensive microgrids may have more difficultly than microgrids with other means of power generation to achieve islanding, since solar radiance values fluctuate considerably during the year there are times where

energy output may decrease considerably. Additionally, without expensive battery stores it would be impossible to conduct operations at night. Goodrich states that because "solar insolation values fluctuate considerably, it is possible to find periods during the year when very little energy is available" Therefore, it's imperative that we "emphasize the benefit of extending island time to remove short-term fluctuations in solar production" (Goodrich, James, Woodhouse, 2012). Additional measures, such as installing a portfolio of energy solutions, can stabilize the effect of fluctuations in solar energy.

4. Distributed Generation

Even if a microgrid is designed to work in isolated operation from the commercial grid, transition issues between the two architectures can still be an issue. Depending on the design of the microgrid there may be a requirement to start local electrical generation mechanisms if power from the commercial grid is lost. If a seamless power transition is required, meaning there is no down time experienced during transition; distributed generation systems must be included in the microgrid design. This seamless transition process is called "intentional islanding." (Ye, Walling, Miller, Du, Nelson, 2005). NREL states that "to prevent the large voltage and frequency transients that follow the loss of the main grid, the intentional islanding control must be capable of maintaining voltage and frequency regulation while exhibiting fast transient disturbance rejection qualities. The distributed generation (DG) must be able to support transient and temporary currents far in excess of the connected load demand because of magnetizing inrush and motor dynamics" (Ye, Walling, Miller, Du, Nelson, 2005).

5. Summary

Production Plan Barstow's state of energy security is in need of repair, and the responsibility of producing and delivering reliable energy has indeed transferred to our stakeholders. Attached to a potentially vulnerable commercial utility circuit that's consistently in the top third of poorest circuit reliability, PPB suffers an average of 3.83 hours of downtime per year. Therefore it's imperative that we understand the Marine Corps installation energy objectives, our operational environment, the concepts of VEES,

the LCOE, and RE cost factors, so we can set the conditions for analyzing the NPV of energy security investments.

Based on the research presented in this chapter, PV and microturbines are the two technologies that lend themselves to further data analysis in chapter 4, but it’s important to note that additional power generation sources alone are not enough to ensure power resiliency. Microgrids are another component to achieving energy security, and function as a proactive means to transition to islanding activities while ensuring operational stability. Due to fluctuations in solar radiance, the recommended microgrid architecture is based on the Type 2b High penetration PV design and integrates microturbines and batteries, with units for power distribution, load balancing, control and intentional islanding.

Carrying our data from chapters 1 and 2, we’ll transition to the methodology chapter of this study, as a means to explain to the reader how we synthesized the data and to act as a connecting file to our analysis in chapter 4.

III. METHODOLOGY

A. PRODUCTION PLANT BARSTOW ENERGY RESILIENCY PROJECT

1. Introduction

Our methodology chapter begins with the assumptions that we made about the present and future condition of PPB and its land area, RE and alternative technology, and the cost factors. We discuss energy normalization, or how we manipulated the data to translate across energy platforms for the purpose of measuring power and cost. We also discuss how we calculated the Value of Electrical Energy Security at PPB, annual power generation of microturbines and PV systems, calculating the lifecycle costs of microturbines, PV and microgrid systems, and finally how we determined the NPV of each.

2. Assumptions

We accepted the assumptions for the PPB energy resiliency project to be true based on historical reference or industry standards, i.e. the opportunity cost for installing the PV array at the Yermo Annex was greater than the value of the land, or PV technology has an industry standard of 0.5% loss of PV generation per year. Our assumptions are as follows:

- The opportunity cost of using land for a solar project has a positive benefit
- There will be no major increases or decreases to PPB's electricity demand and electrical architecture
- There will be no change to PPA terms and incentive timelines as described in the DSIRE database
- There is 0.5% loss of PV generation per year, based on industry standards.
- We assume a two percent increase in the PPA rate per year based on the Yermo Annex contract

- National pricing trends for PV will remain constant with US Department of Energy predictions
- Any generation by installed resources is consumed on-site (no buy-back). This assumption is based on SCE's policy of restricting power transmission back onto their electrical grid for safety purposes.

3. Energy Data Normalization

PPB energy usage data was provided by Mr. Tony Mesa, the base energy manager and electrical units are measured in \$/kWh or \$/mWh at a conversion rate of:

$$\text{kWh} = \text{mWh}\ x\ 1000$$

The data collected is for FY14, and is measured by twenty-four separate building meters each month. Microturbine systems operate at British Thermal Rate (BTU) per kWh (kWh/BTU), where 1BTU = 0.000293 kWh.

B. PEAK SITE LOAD

Due to the fact that the energy data is recorded monthly, the peak site load is approximate to the largest amount of electricity used per hour in the highest month of electricity use of August. We determined the hourly rating by using plant operation data provided by Mr. John Peterson, the Facilities Engineer at PPB. The production plant operates from 0600-0100 Monday through Friday and 0600-1530 on Saturdays. There were twenty-one full work days in the month of August, with 19 production hours for each day. There were five Saturday half-days with 9.5 production hours for each day. Using both sets of data we created the following formula and determined peak site load:

$$\text{Peak Site Load} = \frac{mWh}{\begin{array}{c}(\#\ of\ Full\ Work\ Days\ x\ Production\ Hours) + \\ (\#\ of\ Half\ Days\ x\ Production\ Hours)\end{array}}$$

$$or$$

$$3.46mWh = \frac{1579.5mWh}{(21\ Days\ x\ 19hrs) + (5\ days\ x\ 9.5hrs)}$$

This method assumed that no power was used during non-operating hours, which is incorrect, however the power used during the five non-operating hours is marginal for

the purposes of the determining peak site load handling. Peak site load metrics were supported by Mr. Peterson's professional opinion. (However, we recommend additional peak site load testing for verification).

Additional consideration for peak site load handling is the efficacy of microturbine systems, and their efficiency during ambient air temperatures of 80° F or higher. Capstone states that the efficiency rating of microturbine systems is 33 percent at sea level, plus or minus 2 percent, and that efficiency decreases by 3 percent at 80° F and 5 percent at 120° F (Capstone, 2009). To account for the latitude in efficiency, all kWh microturbine power output calculations are conducted at the advertised low efficiency rating of 31 percent, assuming that the average daily temperature in Barstow is 65.05 ° F. To account for lower efficiency during higher ambient temperatures, we recommend using a combination of solar and microturbines, as solar radiance will be at its highest during the summer months and will decrease the load demand on the microturbines. In order to ensure adequate power during peak hours, we assumed a .5mW allowance and that all recommended systems or a combination thereof produce a minimum of 4mWh.

C. CAPITAL INSTALLATION COSTS

For the capital installation costs of PV we used 2014 data provided by NREL for the national and CA median dollar per watt ($/W) installed, and extrapolated the cost to dollar per kW ($/kW) (Feldman, et al, 2014). For the capital installation costs of microturbines we used the Capstone advertised rate for a C1000 system and then determined the $/kW by dividing the capital cost of installation by 1,000. In order to support PPB's peak load, we multiplied the $/kW by 3,500.

D. POWER GENERATION

In this section, we calculate the production capacity for PV and microturbines and discuss how we apply the PPA rate to the energy output of PV systems.

1. Photovoltaic

In order to understand the 2014 power generation $/kW for PV systems, we based our calculations on data provided to us by MCLB Barstow for the Yermo Annex 772 kW PV

array. We determined the hourly production rate per month by multiplying 772kWh by the number of hours in each month, and we found the monthly efficiency rating by dividing the monthly kWh production rate by its hourly production rate. We established the $/kWh of PV generation from a National Resource Energy Laboratory 2014 study, *Photovoltaic System Pricing Trend* and assumed a 0.995 reduction in PV generation per year after year one (Feldman, et al, 2014).

Our next step was to scale the array to support our peak site load. Using a scaling factor of 4.53, or 3500kWh divided by 772kWh, we calculated the amount of PV production needed per month. Then we determined the physical size of the array by using PV panel size data gathered from NREL. Since PV industry panel efficiency varies, we used the most efficient and least efficient designs to create a high and low estimation of size. After converting the panel size efficiency into w/M^2, we converted the peak load of the PV array into watts and divided it by the efficiency rating, giving the square meters of the array. By using a factor of one square meter per .00025 acres, we determined that at a panel efficiency rate of 175w/M^2 and 125w/M^2, the acreage is equal to 4.94 and 6.92 respectively.

2. Microturbine

Per the Capstone Corporation, a C1000 microturbine system uses 11,000BTUs to create 1kW of power. Since BTUs are sold in MMBTU units, we divided 1 million by 11,000 thousand for the kW/BTU system output. Power output for a low pressure NG C1000 system is approximately 95 percent of 1,000kW; therefore we multiplied the kW/BTU system output by .95, giving us a product in kW/MMBTUs. Then we determined the $/kWh by dividing the $/MMBTUs by kW/MMBTUs. We determined the annual microturbine kWh power production needed by subtracting the total yearly power generated by a 3.5 mWh PV array from PPB's baseline electricity usage, assuming that microturbine production can be equal to zero or 100 percent. Without PV generation we assumed that utility usage plus microturbine production is equal to the PPB baseline electricity usage.

3. Power Purchase Agreement

The PPA rate for PV is determined by investigating the state and federal incentives for PV generation and verifying the PPA rate via the Yermo PV array contract. Assuming a 2 percent increase in the PPA rate per year based on the Yermo contract, and a 0.5 percent decrease in PV generation per year, we calculated the annual cost of PV PPA generated electricity after year one for a twenty year period using the following formula:

$$\text{Annual Cost of PV PPA Generation per Year} =$$

$$(Previous\ Year\ PV\ kWh\ produced\ x\ 0.995) x\ (Previous\ Year\ PPA\ Rate\ x\ 1.02)$$

The PV PPA cost is compounded annually and is in nominal dollars.

E. ANNUAL COSTS OF POWER GENERATION

To calculate the yearly costs of utility with a PV system after year one for a twenty year period, we assumed a two percent yearly increase in utility costs based on historical SCE pricing data and used the following formula:

$$\text{Cost of Utility with a PV PPA} =$$

$$\left(Utility \frac{\$}{kWh} x\ 1.02\right) + (Year\ One\ Utility\ Usage - Annual\ PV\ PPA\ Generation)$$

To calculate the annual cost of microturbine power generation, after year one for a twenty year period and assuming a two percent yearly increase in NG prices, we used the following formula:

$$\text{Annual Cost of Microturbine Power Generation} =$$

$$\left(Microturbine \frac{\$}{kWh} x\ 1.02\right) x\ PPB\ Baseline\ Electricity\ Usage$$

To calculate the cost of microturbine power generation with a PV PPA generation system, after year one for a twenty year period and assuming a two percent yearly increase in NG prices, we used the following formula:

$$Yearly\ Cost\ of\ Microturbine\ Energy\ Production\ with\ a\ PV\ PPA =$$

$$\left(Previous\ Year\ Microturbine\ \frac{\$}{kWh}\ x\ 1.02\right)\ x\ (PPB\ Baseline\ Power\ Usage - Current\ Year\ PV\ PPA\ Generation)$$

If no actions are taken we assume a two percent increase in utility costs per year.

Once we determined the 20 year costs for the PV PPA, and the 20 year power generation costs for PV and microturbines, we determined the annual costs of combining the technologies with the annual cost of the PV PPA, including the published costs of O&M and the capital costs of installation.

F. MICROGRID COSTING

1. Overview

We used three data points for determining the cost of microturbine systems. Our first two data points are via the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP), two of the DOD's environmental research programs. In the first study, the SERDP and ESTCP conducted a cost and performance report about advanced microgrid control technologies on existing microgrid architectures using distributed energy resources at the Twentynine Palms Marine Corps Air Ground Combat Center in Twentynine Palms, CA (ESTCP, 2013). In the second study, they conducted a cost and performance report on a grid-tied microgrid integrated with on-site RE and distributed generation technology located in Fort Bliss, TX (ESTCP, 2012). The outputs of both studies show increases in efficiency, cost savings energy security and reduced emissions in regions environmentally similar to PPB, but even more important to this study they provide a breakdown of microgrid costing by cost element. The third data point for microgrid costing came from the Naval Facilities Engineering Command, and included a cost breakdown for the microgrid project aboard Marine Corps Air Station Miramar, Miramar, CA.

2. Data Normalization

The two SERDP projects measure costing elements in kWh for hardware, and flat rate costing for software and services, while the Miramar project measures costing elements in cost per unit. To derive the cost of the SERDP projects, we multiplied the $/kWh per element by the peak site load and added the flat rate costing for services at a scaled percentage. To derive the levelized cost per kWh of the Miramar system across all energy options, we took the PPB 2014 energy usage baseline, multiplied it out through 20 years, and divided that total kWh production by the total cost of the system. We used the average of the two systems and determined a baseline cost for a microgrid system, minus the cost of generation systems.

Note that the cost of the microgrid system also includes the cost of sixteen on-site Compressed Natural Gas (CNG) tanks for seven days of operation during a sustained natural gas outage and the costs of a battery back-up capable of providing peak site load power for fifteen minutes in support of intentional islanding.

G. OPERATIONS AND MAINTENANCE

Operations and maintenance are costs associated with operating and maintaining equipment. For this study we determined the O&M costs for microturbines and PV systems so we could determine the levelized cost of energy and apply it over a twenty year period.

1. Microturbines

We assumed that PPB would invest in four Capstone C1000 microturbine systems, with a 95 percent efficiency rate equivalent to 950 kWh per engine hour. Using Lazard's median levelized costs of Operations and Maintenance (O&M), we converted engine hours into the amount of kWh produced and then divided the hourly O&M costs by kWh produced per hour.

$$1\ Engine\ hour = 950\ kWh$$

$$950\ kWh = \$Median\ O\&M$$

$$\frac{\$Median\ O\&M}{950\ kWh} = \$.\ O\&M\ Cost\ per\ kWh$$

2. Photovoltaic

We derived the O&M costs for PV generation from Lazard's Levelized cost of Energy. Lazard's study details the high and low fixed O&M costs for utility sized solar, for which we took the high and scaled to a size of 3.5mW.

H. ANNUAL COST OF POWER INTERRUPTION

We calculated the annual cost of power disruption by using the VEES framework. As stated in chapter 2, the VEES framework is comprised of three components: (1) the Customer Damage Function (CDF), or "the value in dollar per kilowatts ($/kW) peak of an outage cost obtained from the CDF curve for a specified duration of the interruption" (Giraldez, et al, 2012). For this study we used the total $/kW of PPB workforce indirect and direct labor wasted during sustained power interruptions at PPB, (2) the peak site load, or the maximum amount of power used by PPB at a given time, and (3) the annual number of outages, or the reliability of the power infrastructure at PPB.

1. Value of Electrical Energy Security

The VEES calculation is used to determine the Value of Electrical Energy Security for PPB:

$$\text{VEES} = Ann\ \#of\ outages\ x\ CDF\ \left(\frac{\$}{kW\ Peak\ Site\ Load}\right)\ x\ Peak\ Site\ Load\ (kW)$$

a. Annual Number of Outages

Using data provided by SCE from 2008-2013, we calculated an average of 1.531 sustained outages per year with an average of 229.593 minutes of sustained outage time per year, where sustained outages are greater than or equal to five minutes. Although Barstow experiences temporary outages each year, the data is not published by SCE. In this study we assumed that the number of outages less than five minutes in duration are a hidden cost and reinforce the value of energy security.

b. Customer Damage Function

The CDF is the cost of direct and indirect labor in PPB's total workforce that's wasted during a sustained outage, multiplied by the average total minutes of a sustained outage.

c. Peak Site Load

The peak site load is determined by the following formula:

(1)

$$\text{Peak Site Load} = \frac{mWh}{(\#\ of\ Full\ Work\ Days\ x\ Production\ Hours) + (\#\ of\ Half\ Days\ x\ Production\ Hours)}$$

$$or$$

$$3.46mWh = \frac{1579.5mWh}{(21\ Days\ x\ 19hrs) + (5\ days\ x\ 9.5hrs)}$$

I. NET PRESENT VALUE

Finally, we determined the yearly cash flow by applying the standard Net Present Value formula:

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_T}{(1+r)^T}$$

THIS PAGE INTENTIONALLY LEFT BLANK

IV. DATA ANALYSIS

A. INTRODUCTION

This chapter focuses on comparing the cost of several energy options that provide power resiliency to PBB through a type 2B microgrid system. We combined the totality of generation installation cost, O&M, fuel, and microgrid controllers for several different generation systems. We then compared these systems to the current method of power generation at PPB, purchase from commercial utility, and found NPVs for all energy options.

B. CURRENT ENERGY USAGE

Metering data provided by MCLB Barstow for PPB is on a monthly basis; therefore it is not possible for us to define a true peak load. We used average working hours per month to determine the average load during working hours. PPB personnel work in two shifts, from 0600 to 1530 and 1530 to 0100, and an additional shift works Saturdays from 0600 to 1530. This equals a 104.5 hour work-week not including holidays. Figure 10 displays the average mW use per hour, based on work-hours and total work-hours per month.

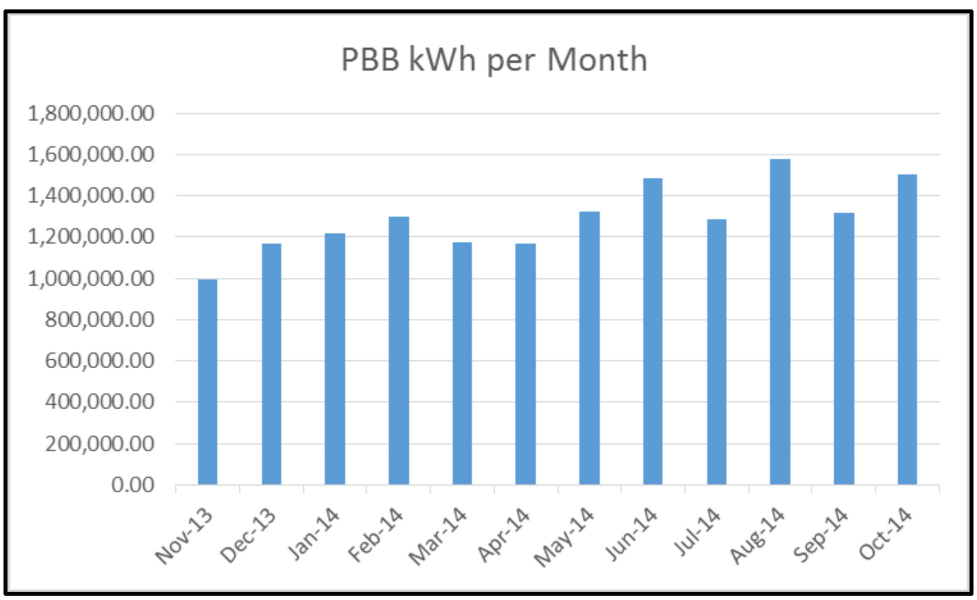

Figure 10. Production Plant Barstow's kWh Usage per Month FY 14

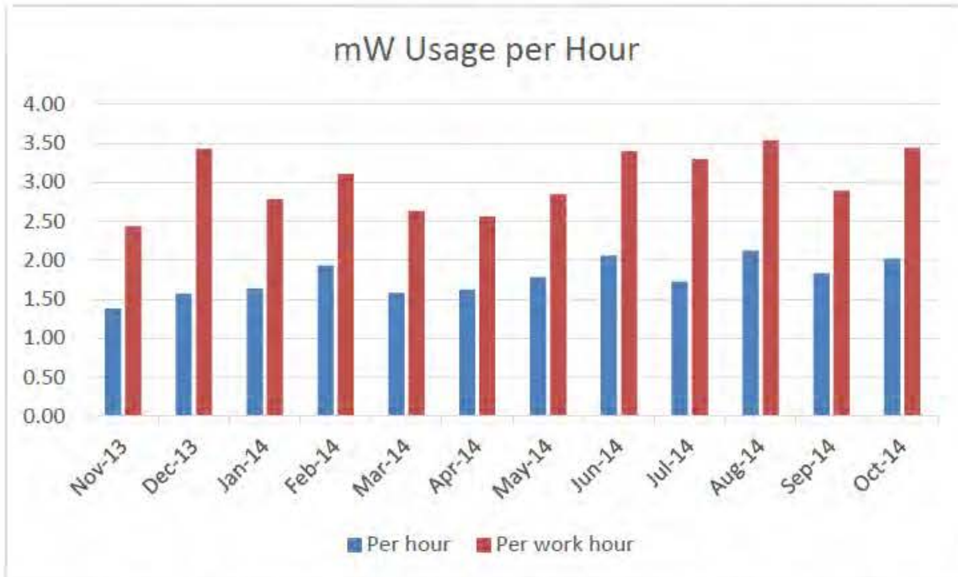

Figure 11. Production Plant Barstow's Energy Usage per Hour and per Work Hour in Megawatts

The work-hour calculations assume that no power is used during non-working hours, so we conclude that a 3.5MW peak load is approximate during regular operations.

C. PPB USAGE COST

In FY14 PPB was charged two different electricity rates from SCE, the change occurring December 31, 2013. SCE's Annual Year (AY) 13 rate was $.1395 per kWh and in AY14 it was reduced to $.1263 per kWh. Using the rates and the total kWh usage, we determined the cost of electricity in FY 14 for PPB, as shown in Table 1.

Month	**kWh**	$ / kWh	Total
Nov-13	994,296.00	0.1395	$138,704.29
Dec-13	1,171,128.00	0.1395	$163,372.36
Jan-14	1,215,938.00	0.1263	$153,572.97
Feb-14	1,297,672.00	0.1263	$163,895.97
Mar-14	1,175,213.00	0.1263	$148,429.40
Apr-14	1,167,229.00	0.1263	$147,421.02

May-14	1,324,010.00	0.1263	$167,222.46
Jun-14	1,483,933.00	0.1263	$187,420.74
Jul-14	1,284,166.00	0.1263	$162,190.17
Aug-14	1,579,501.00	0.1263	$199,490.98
Sep-14	1,319,522.00	0.1263	$166,655.63
Oct-14	1,503,171.00	0.1263	$189,850.50
Total	**15,515,779.00**		**$ 1,988,226.48**

Table 1. Production Plant Barstow's FY 2014 Electric bill

D. YERMO ANNEX ARRAY PPA AND PV PROPOSAL

1. Production and Efficiency

In November 2013 MCLB Barstow entered into a power purchase agreement with SunDurance Energy for the operation of their 772 kW PV array. Due to its relatively short operation time, the long term production data is not available. However, using the thirteen months of available production data (Figure 12) we conducted an analysis on the power generation of a 3.5 MW PV System. By taking the 772kW generation and dividing it by the hours in a month, we derived a monthly efficiency rating for the 772 kW PV System (Figure 13).

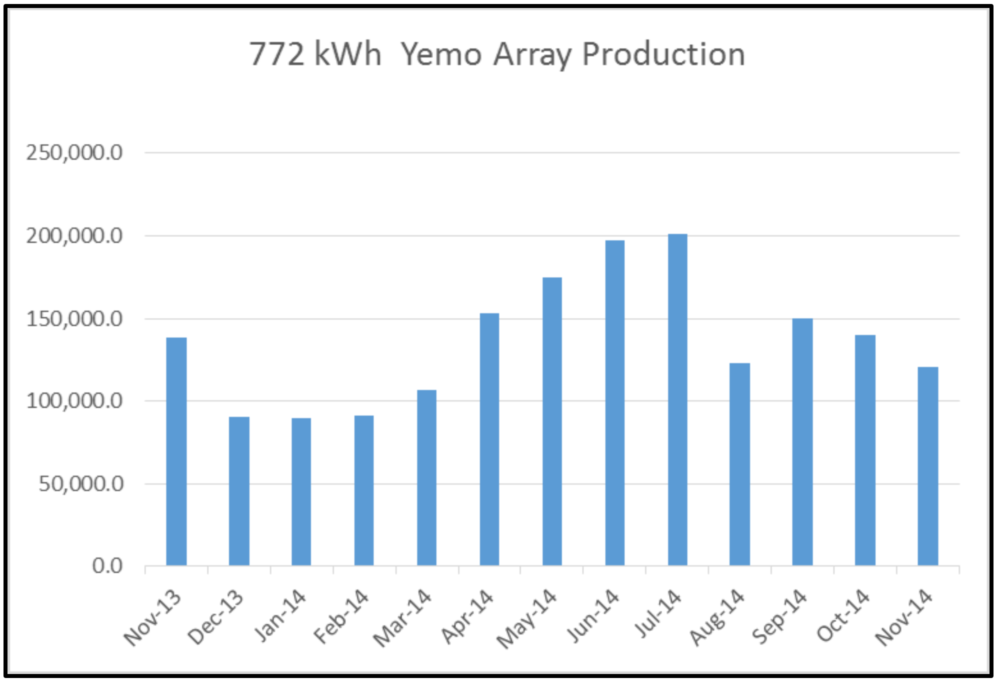

Figure 12. MCLB Yermo Annex 772 kW PV Array kWh Production

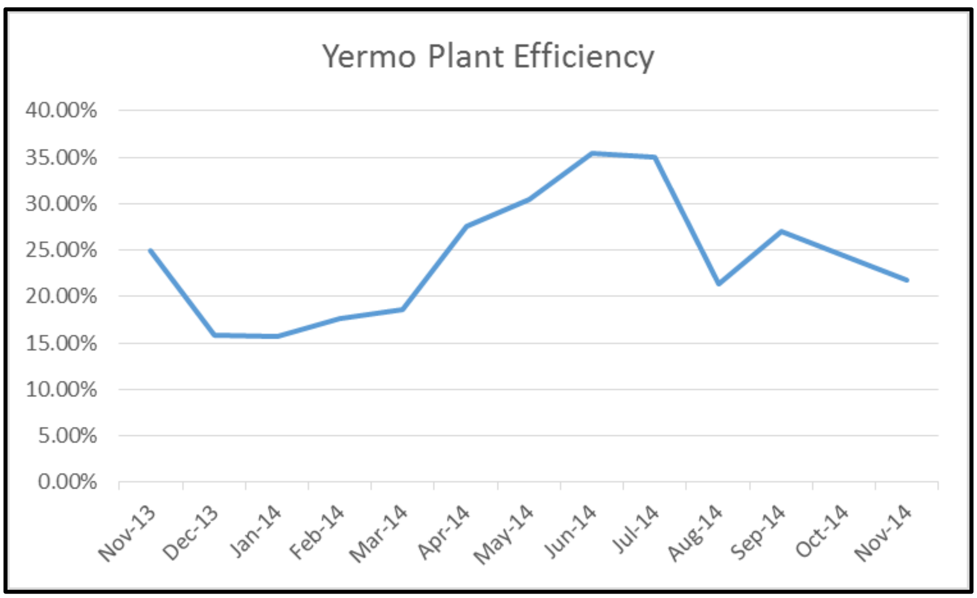

Figure 13. PV Array Production Efficiency

2. Array Scaling

Using the PV efficiency ratings we determined the kWh that would be produced on a larger system using a scaling factor. Our analysis is based on a system rated at 3500kW, which gives us a scaling factor of 4.53.

$$\frac{3{,}500\ kW}{772\ kW} = 4.53$$

3. PV Generation

The scaling factor assisted us in predicting PV generation, as shown in Table 2. PV production will vary more on a yearly basis than traditional power generation sources due to their reliance on sunlight hours. All calculations are based on the FY14 data, and our sensitivity analysis includes factors for different potential rates of PV generation. The current PPA with SunDurance Energy is based on a twenty year contract, with MCLB Barstow paying per kWh used on an increasing yearly rate schedule of approximately two percent. Our analysis includes the same PPA rate schedule for a 3.5 MW system, which includes all capital installation cost and O&M since they would be the burden of the contractor.

Estimated 3.5 mWh PV Generation		
Scaling factor of 4.53 (3,500 kWh / 772 kWh)		
Month	**3.5 mWh Array kWh production**	**mWh Produced**
Dec-13	410,796.63	410.80
Jan-14	407,351.04	407.35
Feb-14	414,922.28	414.92
Mar-14	484,060.88	484.06
Apr-14	692,972.80	692.97
May-14	794,073.83	794.07
Jun-14	893,633.42	893.63
Jul-14	912,448.19	912.45
Aug-14	555,919.69	555.92
Oct-14	633,400.26	633.40
Sep-14	681,139.90	681.14
Nov-14	547,713.73	547.71
Total	**7,428,432.64**	**7,428.43**

Table 2. Predicted 3.5MW PV Array Monthly Production

The output of the analysis provides a baseline of 7,428.43 mWh produced per year.

4. Power in Excess of PV Systems

It's important to note that PV systems experience a 0.5 percent loss of maximum output per year; therefore we used the same metric for our yearly PV power generation analysis. Any additional power generation needs exceeding that of a local PV system is assumed to be the 2014 PPB baseline electricity usage, minus the predicted PV generation. Figure 14 shows the amount of annual power generation that is required in excess of PV generation over a period of twenty years.

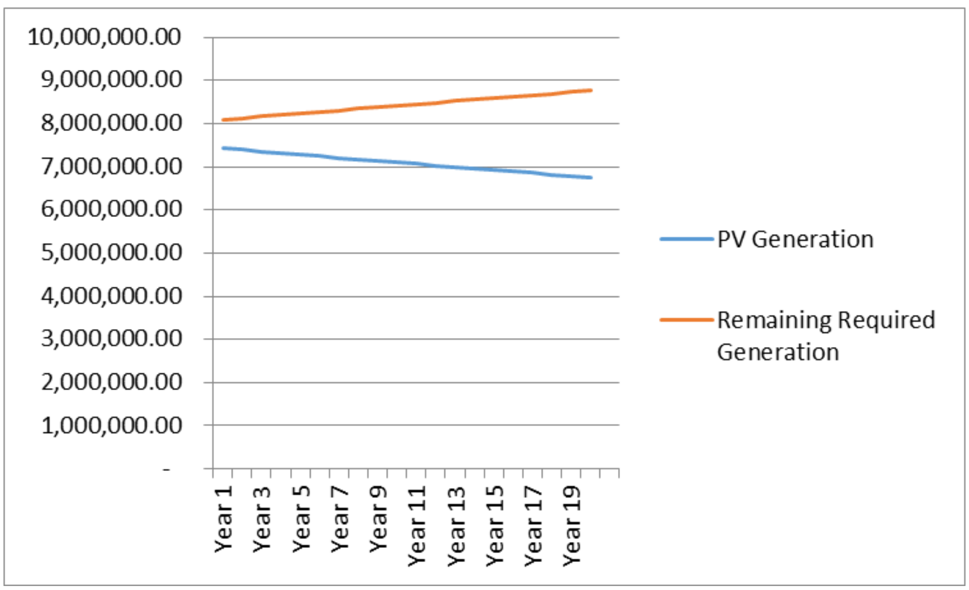

Figure 14. PV generation year 1 through year 20

In year twenty the PV generation is expected to be 6,753,606.05 kWh, requiring 8,762,172.95 kWh of power generation by alternate sources, assuming there is no change in PPB's electricity demand. If PPB choses to pursue a PPA, we can reasonably assume that the purchase rate will be similar to the current PPA purchase rate, which includes Federal and State incentives. The current contracts purchasing schedule is below (SunDurance).

Year	Price /kWh
1	$0.0725
2	$0.0740
3	$0.0755
4	$0.0770
5	$0.0785
6	$0.0801
7	$0.0817
8	$0.0833
9	$0.0850
10	$0.0867
11	$0.0884
12	$0.0902
13	$0.0920
14	$0.0938
15	$0.0957
16	$0.0976
17	$0.0996
18	$0.1016
19	$0.1036
20	$0.1057

Table 3. Twenty Year SunDurance PPA Price Schedule per kWh consumed

5. Capital Cost and O&M

A 2014 NREL study established the CA median price of installed utility PV systems greater than 100kW is $4.26 per watt installed (NREL 2014, September 22). We used the same metric to determine the capital cost of a 3.5MW system, amounting to $14,910,000.00 without financing or federal and state incentives.

$$3{,}5000{,}00\ watts * \$4.26 = \$14{,}910{,}000.00$$

Lazard's study on the Levelized Cost of Energy calculates a fixed O&M cost for utility PV has a range of $13 - $20 per kW installed, per year. Using Lazard's costs for O&M we determined that a 3.5 MW System has a range of $45,500 to $75,000 in O&M cost per year - equating to $.0061 and $.0094 of O&M per kWh produced, respectively. We used the high range estimate and applied $75,000 of annual O&M to an installed PV System.

E. MICROTURBINES

1. Capital Cost

Cost estimates for installing NG microturbines are difficult to obtain due to various system configuration and differing conditions at each respective installation site. Each site may require certain structural improvements, generation unit housing, adapters, accessories etc.

We used three data points to determine the costs of microturbines. Using data from Lazard we estimate a levelized installation cost of $2,300 – $3,800 per kW (Lazard, 2014). Note that Lazard’s levelized cost includes the cost of financing, which our analysis does not initially include. Capstone estimates the general installation cost of a 1,000kW microturbine at $1,635,432, including financing (Capstone, 10 things). Additionally, data provided by NAVFAC revealed that a 4mW NG Generator installed at Marine Corps Air Station Miramar had a total cost of $3,603,000, equating to $900,750 per installed MW.

$$\frac{\$3,603,000}{4MW} = \$900,750\ per\ MW$$

As a baseline we used Capstone’s capital cost of installation.

2. Operations & Maintenance

O&M costs range from $18 to $22 dollars per engine hour (Lazard) and we conducted our analysis using $22 to avoid underestimating costs. In our analysis we assume PPB will use four Capstone C1000 microturbines, with a 95 percent efficiency rating, equating to 950 kWh per engine hour. We converted the engine hours into kWh produced and divided hourly O&M by kWh. The result is an O&M cost of $.0232 per kWh produced.

$$1\ Engine\ hour = 950\ kWh$$

$$950\ kWh = \$22\ O\&M$$

$$\frac{\$22}{950\ kWh} = \$.0232\ per\ kWh$$

Energy portfolios with differing technology will yield dissimilar engine hours for microturbines, which affects fuel usage and O&M.

3. Microturbine kWh BTU Conversion and Fuel Cost

C1000 Capstone Microturbines have a heat rate of 11,000 BTUs per kWh and a thirty-three percent efficiency baseline, plus or minus two percent. The conversion rate is 3,412 BTUs to 1 kW. Using a rate of $4.50 per MMBTUS we calculated that the energy input required for a C1000 microturbine is $.0521 per kWh for year 1. To calculate MMBTUs per kWh, we used the following efficiency factor:

$$\frac{3{,}412\ BTUs}{11{,}000\ BTUs} = .31$$

$$\frac{1{,}000{,}000\ BTUs}{11{,}000\ BTUs} = 90.91\ kWh\ per\ MMBTUs$$

The C1000 produces 950 kWh per rated 1,000 kWh, an efficiency factor of .95. Therefore the kWh per MMBTUs is:

$$90.91\ kWh\ per\ MMBTUs * .95 = 86.36\ kWh\ per\ MMBTUs$$

Using the 86.36 kWh per MMBTUs we can find the price per kWh by dividing the price of 1 MMBTUs by 86.36 kWh per MMBTU:

$$\frac{\$4.50\ per\ MMBTU}{86.36\ kWh\ per\ MMBTU} = .\$0521\ per\ KwH$$

F. COST PER KILOWATT HOURS VIA DIFFERENT GENERATION METHODS

1. Utility Grid

PPB’s current utility rate is $0.1263 per kWh. The following table shows the assumed cost of utility generated electricity using a two percent escalation rate per year, over a period of twenty years. Since electricity is being purchased from a commercial utility, O&M is incumbent on the contractor and not a factor in the price point.

Year	Price / kWh
1	$0.1263

2	$0.1288
3	$0.1314
4	$0.1340
5	$0.1367
6	$0.1394
7	$0.1422
8	$0.1451
9	$0.1480
10	$0.1509
11	$0.1540
12	$0.1570
13	$0.1602
14	$0.1634
15	$0.1667
16	$0.1700
17	$0.1734
18	$0.1769
19	$0.1804
20	$0.1840

Table 4. 20 Utility Escalation Price per kWh

2. Power Purchase Agreement

O&M and capital costs are not included in any kWh price for a PPA because they are the burden of the contractor, not the stakeholder.

3. PV Install

The price per kWh with a PV install includes several factors. There is the capital cost of construction, O&M, and the decreasing annual efficiency. Because of the annual reduction in efficiency per year the price per kWh will increase inversely to the loss. Fixed O&M is assumed to be between $13 and $20 per kW installed per year. This study uses $20 as a baseline to avoid underestimation and is adjusted during the sensitivity analysis. This study also uses $4.26 per installed watt based on the 2014 NREL study (NREL 2014 Photovoltaic System Pricing Trends). Table 5 displays all included costing

data and shows an estimate of the per kWh cost for installed PV in year one. Capital cost is inputted at 1/20th of the total capital cost.

Year	Capital cost	O&M	Efficiency	kWh Produced	Cost per kWh
1	$745,500.00	$47,250.00	100%	7,428,432.64	$0.1067
2	$745,500.00	$47,250.00	99.500%	7,391,290.48	$0.1073
3	$745,500.00	$47,250.00	99.000%	7,354,148.32	$0.1078
4	$745,500.00	$47,250.00	98.500%	7,317,006.15	$0.1083
5	$745,500.00	$47,250.00	98.000%	7,279,863.99	$0.1089
6	$745,500.00	$47,250.00	97.500%	7,242,721.83	$0.1095
7	$745,500.00	$47,250.00	97.000%	7,205,579.66	$0.1100
8	$745,500.00	$47,250.00	96.500%	7,168,437.50	$0.1106
9	$745,500.00	$47,250.00	96.000%	7,131,295.34	$0.1112
10	$745,500.00	$47,250.00	95.500%	7,094,153.17	$0.1117
11	$745,500.00	$47,250.00	95.000%	7,057,011.01	$0.1123
12	$745,500.00	$47,250.00	94.500%	7,019,868.85	$0.1129
13	$745,500.00	$47,250.00	94.000%	6,982,726.68	$0.1135
14	$745,500.00	$47,250.00	93.500%	6,945,584.52	$0.1141
15	$745,500.00	$47,250.00	93.000%	6,908,442.36	$0.1148
16	$745,500.00	$47,250.00	92.500%	6,871,300.19	$0.1154
17	$745,500.00	$47,250.00	92.000%	6,834,158.03	$0.1160
18	$745,500.00	$47,250.00	91.500%	6,797,015.87	$0.1166
19	$745,500.00	$47,250.00	91.000%	6,759,873.70	$0.1173
20	$745,500.00	$47,250.00	90.500%	6,722,731.54	$0.1179

Table 5. Twenty Year Outlook of PV Install Price per kWh

These prices do not reflect any Federal or State subsidies and incentives that lower the coast of any PV install significantly. The PPA that PPB Barstow has entered already captures some these subsidies and incentives and therefore is significantly cheaper than levelized cost of a PV install.

4. Microturbines

We assume that any installed microturbine capacity should exceed the PPB peak site load in order to facilitate islanding capabilities; therefore we used the price baseline for four C1000 systems. Analysis discussed later in the study displays the cost through different energy options. Using the same O&M costs of $.0211 per kWh, and a cost of $4.50 per

MMBTU for year one, we determined a cost of $.0852 per kWh if microturbines provide all of the power for PPB. Microturbine use varies depending on the energy portfolio selected. System usage greatly affects the cost per kWh due to the engine hours and fuels involved. Using the microturbines more will lower the levelized cost per kWh. Assuming that PPB either installs or enters a PPA for a 3.5 MW PV system, and maintains their 2014 baseline electricity usage, the theoretical maximum microturbine generation is the 2014 PPB kWh usage – current year PV generation. If power is generated using the 3.5 PV array at a rate of 7,428,433 kWh and we subtract the PV usage from the PPB's 2014 electricity usage baseline of 15,515,779.00kWh, we conclude a difference of 8,087,346 kWh for theoretical maximum microturbine use in year 1, with it increasing slightly every year due to the decreasing PV generation. In Table 6 we applied the difference in kWh and the capital cost of installation over a period of twenty years, without co-generation, to build a relative price structure.

Year	Capital cost	Fuel cost per kWh	O&M / kWh	kWh Produced	$ / kWh	Total
1	$320,000.00	$0.0521	$0.0232	15,515,779.00	$0.0938	$1,487,766.52
2	$320,000.00	$0.0531	$0.0232	15,515,779.00	$0.0948	$1,503,935.60
3	$320,000.00	$0.0542	$0.0232	15,515,779.00	$0.0959	$1,520,428.06
4	$320,000.00	$0.0553	$0.0232	15,515,779.00	$0.0970	$1,537,250.36
5	$320,000.00	$0.0564	$0.0232	15,515,779.00	$0.0981	$1,554,409.11
6	$320,000.00	$0.0575	$0.0232	15,515,779.00	$0.0992	$1,571,911.04
7	$320,000.00	$0.0587	$0.0232	15,515,779.00	$0.1004	$1,589,763.01
8	$320,000.00	$0.0599	$0.0232	15,515,779.00	$0.1015	$1,607,972.01
9	$320,000.00	$0.0610	$0.0232	15,515,779.00	$0.1027	$1,626,545.19
10	$320,000.00	$0.0623	$0.0232	15,515,779.00	$0.1039	$1,645,489.84
11	$320,000.00	$0.0635	$0.0232	15,515,779.00	$0.1052	$1,664,813.38
12	$320,000.00	$0.0648	$0.0232	15,515,779.00	$0.1065	$1,684,523.40
13	$320,000.00	$0.0661	$0.0232	15,515,779.00	$0.1078	$1,704,627.61
14	$320,000.00	$0.0674	$0.0232	15,515,779.00	$0.1091	$1,725,133.91
15	$320,000.00	$0.0688	$0.0232	15,515,779.00	$0.1104	$1,746,050.33
16	$320,000.00	$0.0701	$0.0232	15,515,779.00	$0.1118	$1,767,385.08
17	$320,000.00	$0.0715	$0.0232	15,515,779.00	$0.1132	$1,789,146.53
18	$320,000.00	$0.0730	$0.0232	15,515,779.00	$0.1146	$1,811,343.20
19	$320,000.00	$0.0744	$0.0232	15,515,779.00	$0.1161	$1,833,983.81
20	$320,000.00	$0.0759	$0.0232	15,515,779.00	$0.1176	$1,857,077.23

Table 6. Microturbine Annual Cost Assuming no Co-Generation

Levelized Year 1 Cost by Generation Source per kWh				
	PPA	MT	PV	Utility
Fuel	$ -	$0.0521	$ -	$ -
O&M	$ -	$0.0232	$ 0.0094	$ -
Capital Cost	$ -	$0.0206	$ 0.1147	$ -
Purchase Rate	$0.0725	$ -	$ -	$ 0.1263
Total	$ 0.0725	$ 0.0959	$ 0.1241	$ 0.1263

Table 7. Levelized cost of generation in year one per kWh

A side by side comparison of all generation sources show that the cheapest way to generate power is through a PPA with incentives and the most expensive is through the current system of purchasing all power directly from a commercial source.

5. Islanding factors

The Table 7 figure does not represent the additional cost of installing a microgrid system. In order to apply a levelized cost per kWh including the microgrid system, we took the PPB 2014 energy usage baseline, multiplied it out through 20 years, and divided that total kWh production by the total cost of the microgrid, $3,216,473.50

$$\frac{\$3{,}216{,}463.50}{20\ Year\ kWh\ usage} = Levelized\ Cost\ per\ kWh$$

$$\frac{\$3{,}216{,}463.50}{310{,}315{,}580.00\ kWh} = \$.0104\ per\ kWh$$

This $.0104 levelized cost per kWh has been applied to every kWh produced in our model (with the exception of the current utility purchase generation method). With this cost included in our data we have all the factors necessary to conduct a twenty year outlook for power generation and evaluate its NPV across all energy options.

G. 20-YEAR NET PRESENT VALUE

To conduct a twenty year NPV analysis we constructed a table to calculate total generation cost per year via several different energy options. The energy options include the energy purchased exclusively from a utility, a 3.5 MW PPA agreement, a 3.5 MW PV system, and microturbine system. In order to generate enough power to meet PPB's 2014 baseline demand, PPB should install some combination of PV, utility, or microturbine generation. Differing combinations will affect the cost of microturbines since their O&M and fuel cost are dependent on usage. The following table shows two options for microturbines, the first assuming that it will generate all of PPB's power, and the second assuming it will generate the difference between PPB's usage and PV production (which will be the same regardless of PPA or PV install). The PV system cost of generation is unique because it only encompasses capital cost of the microgrid, PV installation, and yearly O&M (which is the same regardless of usage).

Cost of Generation In 2014 Dollars							
Year	PPA	PV	Utility	MT	Fuel	MT W/ Cogen	Fuel w/ Cogen
1	$615,558	$922,000	$1,959,643	$840,136	$808,454	$437,907	$421,393
2	$612,481	$922,000	$1,959,643	$840,136	$808,454	$439,919	$423,329
3	$609,418	$922,000	$1,959,643	$840,136	$808,454	$441,920	$425,254
4	$606,371	$922,000	$1,959,643	$840,136	$808,454	$443,911	$427,170
5	$603,339	$922,000	$1,959,643	$840,136	$808,454	$445,892	$429,077
6	$600,322	$922,000	$1,959,643	$840,136	$808,454	$447,863	$430,974
7	$597,321	$922,000	$1,959,643	$840,136	$808,454	$449,824	$432,861
8	$594,334	$922,000	$1,959,643	$840,136	$808,454	$451,776	$434,739
9	$591,363	$922,000	$1,959,643	$840,136	$808,454	$453,718	$436,607
10	$588,406	$922,000	$1,959,643	$840,136	$808,454	$455,650	$438,467
11	$585,464	$922,000	$1,959,643	$840,136	$808,454	$457,572	$440,317
12	$582,536	$922,000	$1,959,643	$840,136	$808,454	$459,485	$442,157
13	$579,624	$922,000	$1,959,643	$840,136	$808,454	$461,388	$443,989
14	$576,726	$922,000	$1,959,643	$840,136	$808,454	$463,282	$445,811
15	$573,842	$922,000	$1,959,643	$840,136	$808,454	$465,166	$447,624
16	$570,973	$922,000	$1,959,643	$840,136	$808,454	$467,041	$449,428
17	$568,118	$922,000	$1,959,643	$840,136	$808,454	$468,907	$451,224
18	$565,277	$922,000	$1,959,643	$840,136	$808,454	$470,763	$453,010
19	$562,451	$922,000	$1,959,643	$840,136	$808,454	$472,610	$454,787
20	$559,639	$922,000	$1,959,643	$840,136	$808,454	$474,447	$456,555
Total	**$11,743,563**	**$18,440,000**	**$39,192,858**	**$16,802,729**	**$16,169,075**	**$9,129,042**	**$8,784,773**

Table 8. Cost of Generation Source Over Twenty Years (in Thousands)

All the values in Table 8 are given in 2014 dollars. In order to capture the NPV we to inflated and discounted the values. In accordance with (IAW) Office of Management and Budget (OMB) Circular 94 we use the inflation rate averaged over the last six years of the presidential budget assumptions for a twenty year analysis (OMB Circular 94). The inflation numbers are derived from OMB Circular 76 which averages to two percent per year. In addition to inflation we must escalate the price of fuel as well. The price of fuel is escalated IAW with the National Defense Budget Estimates, also known as the “Green Book.” Their fuel escalation rates actually provide a negative value over the next 6 years at -0.2 percent (National Defense Budget Estimates for FY 2015 pg. 52) This rate is used for fuel escalation, which when combined with the two percent inflation rate, escalates fuel prices at 1.8 percent per year. Table 9 shows the nominal price of power generation with the above factors included.

Inflated nominal In Thousands of Dollars							
Year	PPA	PV	Utility	MT	Fuel MT	MT W/ Cogen	Fuel w/ Cogen
1	$615,558	$922,000	$1,959,643	$840,136	$808,454	$437,907	$421,393
2	$627,869	$940,440	$1,998,836	$856,939	$824,498	$448,717	$431,730
3	$640,427	$959,249	$2,038,812	$874,078	$840,860	$450,758	$433,693
4	$653,235	$978,434	$2,079,589	$891,560	$857,547	$452,789	$435,647
5	$666,300	$998,002	$2,121,180	$909,391	$874,565	$454,810	$437,592
6	$679,626	$1,017,963	$2,163,604	$927,579	$891,920	$456,820	$439,526
7	$693,219	$1,038,322	$2,206,876	$946,130	$909,620	$458,821	$441,451
8	$707,083	$1,059,088	$2,251,014	$965,053	$927,672	$460,812	$443,366
9	$721,225	$1,080,270	$2,296,034	$984,354	$946,081	$462,792	$445,272
10	$735,649	$1,101,875	$2,341,955	$1,004,041	$964,856	$464,763	$447,168
11	$750,362	$1,123,913	$2,388,794	$1,024,122	$984,004	$466,724	$449,055
12	$765,369	$1,146,391	$2,436,570	$1,044,604	$1,003,532	$468,675	$450,932
13	$780,677	$1,169,319	$2,485,301	$1,065,496	$1,023,447	$470,616	$452,800
14	$796,290	$1,192,705	$2,535,007	$1,086,806	$1,043,757	$472,548	$454,658
15	$812,216	$1,216,559	$2,585,707	$1,108,542	$1,064,470	$474,470	$456,507
16	$828,460	$1,240,891	$2,637,421	$1,130,713	$1,085,595	$476,382	$458,347
17	$845,030	$1,265,708	$2,690,170	$1,153,327	$1,107,138	$478,285	$460,178
18	$861,930	$1,291,023	$2,743,973	$1,176,394	$1,129,110	$480,178	$462,000
19	$879,169	$1,316,843	$2,798,853	$1,199,922	$1,151,517	$482,062	$463,812
20	$896,752	$1,343,180	$2,854,830	$1,223,920	$1,174,369	$483,936	$465,616
Totals	$14,956,4480	$22,402,175	$47,614,168	$20,413,106	$19,613,010	$9,302,865	$8,950,744

Table 9. Cost of Generation Source per Year in Nominal Dollars

With the total power generations per year we derived several different energy portfolios for analysis and comparison to purchasing power from the commercial grid. We conducted an analysis for a PPA with residual power generation via microturbines, a PV install with residual power via microturbines, and power generation generated solely via microturbines. We captured these values and found the difference in price between the utility rate and the different energy portfolios. The difference is the captured savings of installing each system. Applying the yearly savings generated the total savings over twenty years for each energy portfolio.

Savings By source Per Year	PPA + MT	PV + MT	MT
Year 1	$484,783.85	$178,342.18	$342,735.39
Year 2	$490,519.76	$177,949.26	$349,715.41
Year 3	$513,934.14	$195,112.22	$356,837.52
Year 4	$537,916.92	$212,718.57	$364,104.60
Year 5	$562,478.99	$230,776.67	$371,519.61
Year 6	$587,631.42	$249,295.05	$379,085.56
Year 7	$613,385.53	$268,282.43	$386,805.52
Year 8	$639,752.85	$287,747.70	$394,682.62
Year 9	$666,745.17	$307,699.91	$402,720.06
Year 10	$694,374.49	$328,148.33	$410,921.11
Year 11	$722,653.08	$349,102.39	$419,289.08
Year 12	$751,593.42	$370,571.71	$427,827.38
Year 13	$781,208.27	$392,566.13	$436,539.48
Year 14	$811,510.65	$415,095.67	$445,428.90
Year 15	$842,513.83	$438,170.55	$454,499.26
Year 16	$874,231.36	$461,801.21	$463,754.24
Year 17	$906,677.04	$485,998.29	$473,197.59
Year 18	$939,864.97	$510,772.65	$482,833.15
Year 19	$973,809.53	$536,135.36	$492,664.83
Year 20	$1,008,525.39	$562,097.74	$502,696.61
Total	**$14,404,110.65**	**$6,958,384.03**	**$8,357,857.92**

Table 10. Savings per year by Generation Source Compared to Utility

Using the values from Table 10, we applied a yearly nominal discount rate of 3.7 percent, as delineated from OMB Circular 94 for all projects twenty years and over, and calculated annual and lifetime NPV.

NPV Per Annum by Source			
Year	PPA + MT	PV + MT	MT
Year 1	$467,486.83	$171,978.95	$330,506.65
Year 2	$456,140.88	$165,477.39	$325,205.03
Year 3	$460,862.32	$174,963.80	$319,988.40
Year 4	$465,157.67	$183,946.01	$314,855.39
Year 5	$469,042.85	$192,441.23	$309,804.67
Year 6	$472,533.35	$200,466.18	$304,834.91
Year 7	$475,644.23	$208,037.17	$299,944.82
Year 8	$478,390.10	$215,170.04	$295,133.12
Year 9	$480,785.18	$221,880.21	$290,398.56
Year 10	$482,843.29	$228,182.66	$285,739.90
Year 11	$484,577.82	$234,091.96	$281,155.92
Year 12	$486,001.81	$239,622.28	$276,645.43
Year 13	$487,127.89	$244,787.37	$272,207.25
Year 14	$487,968.33	$249,600.60	$267,840.23
Year 15	$488,535.01	$254,074.95	$263,543.21
Year 16	$488,839.48	$258,223.03	$259,315.09
Year 17	$488,892.93	$262,057.07	$255,154.76
Year 18	$488,706.20	$265,588.96	$251,061.12
Year 19	$488,289.80	$268,830.22	$247,033.12
Year 20	$487,653.91	$271,792.03	$243,069.70
Total	$ 9,585,479.88	$ 4,511,212.09	$ 5,693,437.29

Table 11. Annual and total NPV of savings by generation source

This shows a positive NPV for all proposed energy portfolios. It is important to note that these findings also assumed the highest predicted cost for O&M across all energy sources, and a rate of fuel that is significantly over the current market rate. It also included the cost of install for a microgrid and all associated components, as well as a battery bank to facilitate transitioning to islanding activities. It does not capture the VEES savings which are included below at a NPV rate per annum.

H. VEES SAVINGS

Using the VEES calculation we determined a VEES saving of $140,788.02 per year.

$$\text{VEES} = Annual\ \#of\ outages\ x\ CDF\ \left(\frac{\$}{kW\ Peak\ Site\ Load}\right)\ x\ Peak\ Site\ Load\ (kW)$$

$$VEES = 1.531 * \$26.27 * 3{,}500$$

$$VEES = \$140{,}788.02$$

We applied the VEES savings per year, at a 2% inflation rate and discount it back using the nominal discount rate of 3.7% to calculate the yearly NPV of VEES:

20 Year VEES	
NPV	
1	$ 135,764.72
2	$ 133,539.07
3	$ 131,349.91
4	$ 129,196.63
5	$ 127,078.65
6	$ 124,995.40
7	$ 122,946.29
8	$ 120,930.78
9	$ 118,948.31
10	$ 116,998.33
11	$ 115,080.33
12	$ 113,193.77
13	$ 111,338.13
14	$ 109,512.92
15	$ 107,717.62
16	$ 105,951.76
17	$ 104,214.84
18	$ 102,506.40
19	$ 100,825.97
20	$ 99,173.09
Total	$ 2,331,262.92

Table 12. VEES NPV

This value can be added to any of the proposed generation methods to capture more savings.

I. INCENTIVES AND SUBSIDIES

California recently had several renewable energy initiatives and subsidies expire, and if still available, could have lowered the capital cost of RE installation. The California Solar Initiative (CSI) is a fund that was applied toward renewable energy projects and offered heavy subsidies for PV installations. PPB's current PPA with SunDurance captures some of those savings. Due to the CSI, the SunDurance PPA achieved a lower levelized cost than a government-owned PV project. Even though the PV and microturbine energy proposals have positive NPVs, more savings could have been achieved if PPB had taken advantage of some of the CSI's funding. It is unknown if new RE projects are subject to future subsidies, or if any PPA entered would capture the savings that a private contractor has already applied for. Federal subsidies for PV expire in 2016, and the CSI is currently out of funding.

J. 20 YEAR OUTLOOK CONCLUSION

The combined NPV of the proposed energy installations with the VEES makes a strong business case for installing a Type 2B microgrid system

Total 20 year Savings by Source			
	PPA + MT	PV + MT	MT
20 Year NPV	$9,585,479.88	$4,511,212.09	$5,693,437.29
20 Year VEES NPV	$2,331,262.92	$2,331,262.92	$2,331,262.92
Total NPV	**$11,916,742.8**	**$6,842,475.01**	**$ 8,024,700.21**

Table 13. Total NPV by Power Generation Source or Co-Generation Source

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

As a means to meet the needs of our stakeholders and comply with the energy directives set forth by the Commandant of the Marine Corps, we've aligned our research and analysis in this study to create an efficient, resilient, cost effective and secure solution that integrates alternative and RE resources. The following conclusions underline the importance of this study and emphasize the value of energy security.

1. Energy is the Center of Gravity, Substructure is the Critical Vulnerability

Barstow is an area that's abundant in renewable and alternative energy resources. As indicated by solar and wind projects at the Nebo and Yermo Annexes, MCLB Barstow has made a substantial effort to diversify its energy portfolio. However, adding power generation sources is only half the battle of achieving energy security. Microgrids are necessary for power distribution to critical infrastructure, and currently one of MCLB Barstow's most important tenants is bound to an electrical grid that can be defined as unpredictable.

2. Energy Security has a Defined Cost

Some could argue that from a qualitative perspective the quantitative cost of energy security is irrelevant, because the potential unfavorable consequences of underinvesting in energy security are greater than the expenditures to secure against them. Since we can't predict the future and its prospective misfortunes, this argument has some merit. However, by applying the Value for Electrical Energy Security we can better understand the costs of interruption associated with underinvesting in energy security and use it as a metric for mitigating future risk (Figure 15). Additionally, we can use VEES as a way to justify spending for our critical infrastructure.

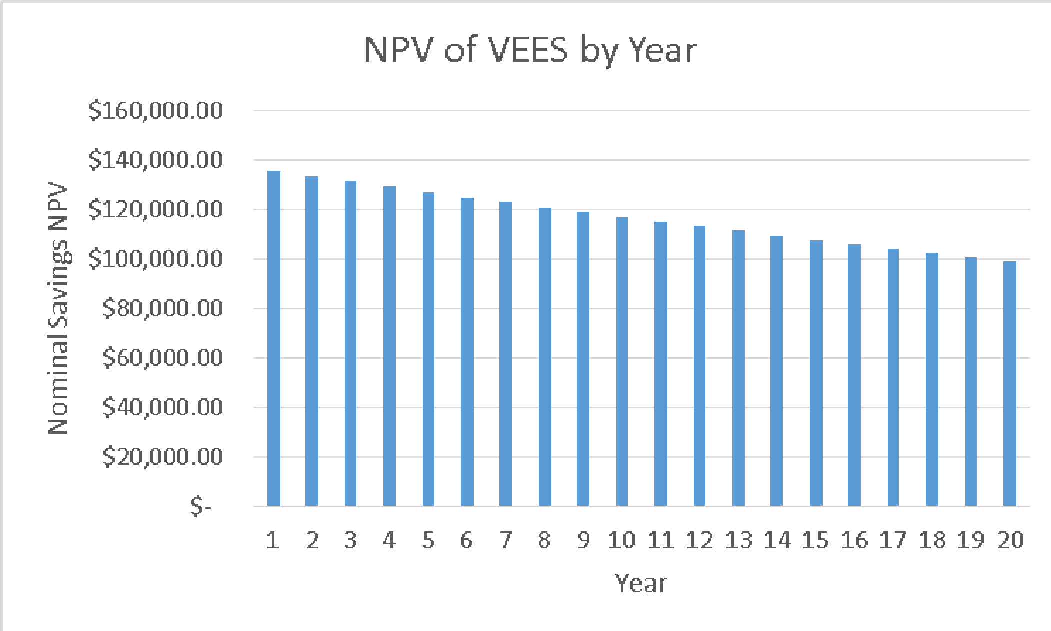

Figure 15. VEES NPV Savings Per Year

3. Energy Security and Environmental Protection are Mutually Supporting

The derivatives of investing in the microgrid technology outlined in this study aren't just an increase in reliability or reduction in cost, there is also strong evidence of environmental benefits in comparison to traditional power generation methods, all of which neatly aligns with policies and mandates set forth by the Marine Corps.

The EPA states that .000069 metric tons of CO2 are emitted for the generation of one kWh of electricity by traditional technology (EPA, 2014). At its current utility baseline electricity usage, PPB greenhouse emissions total 1070.59 metric tons per year, a calculation that based on PPB's electricity usage baseline multiplied by the 000069 metric tons of CO2 are emitted for the generation of one kWh of electricity by traditional technology (EPA.gov, 2014).

Assuming that a 3.5MW PV array generates approximately forty-six percent of PPB's electricity over a period of twenty years, this translates to a reduction of 5816.58 metric tons in emissions per year on average. If coupled with microturbines, another 2613.25 metric tons of greenhouse gasses can be eliminated per year on average,

understanding that emissions reductions may vary based on the generation source of utility grid power. Therefore we can assume that any future investment that PPB makes in microgrid technology assists the Marine Corps in reaching its targets of reducing installation energy consumption by thirty percent and increasing installation RE consumption by fifty percent by 2020.

	Electricity Usage Baseline: 15,515,779 kWh per Year				
Year	Solar kWh Produced	Microturbine kWh Produced	Solar Emissions Reduction (Tons)	Microturbine Emissions Reduction (Tons)	Emissions Reduction Total
1	7428432.64	8087346.36	5125.62	2507.08	7632.70
2	7391290.48	8124488.52	5099.99	2518.59	7618.58
3	7354334.03	8161444.97	5074.49	2530.05	7604.54
4	7317562.36	8198216.64	5049.12	2541.45	7590.57
5	7280974.54	8234804.46	5023.87	2552.79	7576.66
6	7244569.67	8271209.33	4998.75	2564.07	7562.83
7	7208346.82	8307432.18	4973.76	2575.30	7549.06
8	7172305.09	8343473.91	4948.89	2586.48	7535.37
9	7136443.56	8379335.44	4924.15	2597.59	7521.74
10	7100761.35	8415017.65	4899.53	2608.66	7508.18
11	7065257.54	8450521.46	4875.03	2619.66	7494.69
12	7029931.25	8485847.75	4850.65	2630.61	7481.27
13	6994781.60	8520997.40	4826.40	2641.51	7467.91
14	6959807.69	8555971.31	4802.27	2652.35	7454.62
15	6925008.65	8590770.35	4778.26	2663.14	7441.39
16	6890383.61	8625395.39	4754.36	2673.87	7428.24
17	6855931.69	8659847.31	4730.59	2684.55	7415.15
18	6821652.03	8694126.97	4706.94	2695.18	7402.12
19	6787543.77	8728235.23	4683.41	2705.75	7389.16
20	6753606.05	8762172.95	4659.99	2716.27	7376.26
			Average:	Average:	
			4889.302892	2613.248162	

Table 14. Emissions Reductions Over Twenty Years

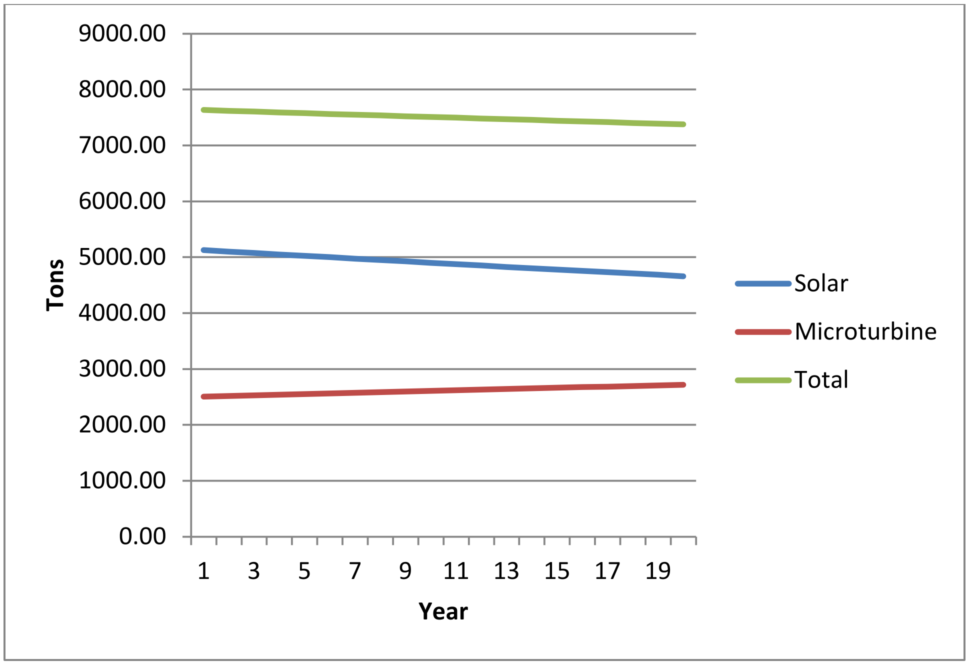

Figure 16. Reduction in Gas Emissions Per Year

4. It's Cheaper in the Long Run

The Net Present Value of investing in a microgrid with RE and alternative generation technologies is greater than continuing to pay for electricity from the utility. Since both the levelized cost of microturbine and PV are lower than the utility rate, the NPV will always be positive regardless of the power generation mix.

Total 20 year Savings by Source			
	PPA + MT	PV + MT	MT
20 Year NPV	$ 9,585,479.88	$ 4,511,212.09	$ 5,693,437.29
20 Year VEES NPV	$931,043.25	$ 931,043.25	$931,043.25
Total NPV	**$10,516,523.13**	**$5,442,255.34**	**$ 6,624,480.54**

Table 15. Net Present Value of Energy Portfolios

5. Every kW Removed is a kW You Don't Pay For

Microgrids and alternative and RE resources can increase efficiency, however additional cost savings can be found in lowering demand at PPB. In an independent study conducted by an energy services provider for Production Plan Barstow, they concluded that a large

potential energy savings per year can be achieved by installing energy efficient equipment. It's important to note that a decrease in demand not only lowers the annual cost of electricity and natural gas, but also lowers the capital cost of installation of energy resiliency systems, due to the potential decrease in the peak site load and power generation scaling.

6. An Energy Framework

Our intent with this study is to create a framework that can be applied to other MCLC tenant commands to meet energy security and energy reduction goals. By investigating available local energy resources, determining the local levelized cost of energy for power generation technologies with and without incentives, calculating the cost interruption, conducting various sensitivity analyses at a range of prices, determining the net present value of a project, and using this study as a data point to cost and scale microgrid systems, future stakeholders can determine the cost-benefit of an energy security project.

B. RECOMMENDATIONS

Our recommendations are as follows:

1. Marine Corps Logistics Command

- Communicate with contractors for cost estimates for the following projects:
  - A 3.5MW PV system
  - 4MW microturbine system
  - Type 2b microgrid system with distributed generation and islanding capability to include a 875kW battery store

3. Create an information network for disseminating federal and state incentives to tenant commands in order to achieve savings via PPAs before they expire.

4. Review how tenant commands capture energy data and implement policies to refine energy data in order to support improved analysis.

2. Future Research

- Determine the cost drivers for microgrid substructure in order to make microgrid costing more accurate.
- Determine measures for decreasing demand at PPB, i.e. study the NPV of energy-efficient equipment.
- Commission a study on temporary and sustained disruptions at Marine Corps Installations to include tenant commands, in order to assign a CDF to each site

3. Limitations

Our study was unable to tell us effective ways for PPB to decrease peak site load through improved work place or equipment efficiencies. These decreases inversely affect the need for more power generation and are a huge element of cost savings. We could not determine future RE or other government incentives that may become available to any future projects. Any future subsidy or incentive would greatly affect the LCOE for our generation portfolios.

The value of the land that would be needed to install a 3.5 mW PV system could not be determined because we are not aware of any alternatives that MCLC would use the land for.

The volatility of energy markets makes any 20 year fuel estimation difficult to assess and future energy prices could shift dramatically greatly lowering or raising the LCOE for microturbine systems.

PV systems are relatively new and few have reached their end of life usage. Without reliable lifetime data it is difficult to ascertain if the .5% efficiency reduction will be a constant, or a variable decline, or even an underestimation or over estimation.

LIST OF REFERENCES

A123 Presentation by Andy Chu, MIT Lincoln Laboratory, November 30, 2011.

AB 2584 Assembly Bill - Bill Analysis. (2014, April 25). Retrieved December 2, 2014, from http://www.leginfo.ca.gov/pub/13-14/bill/asm/ab_2551-2600/ab_2584_cfa_20140425_172026_asm_comm.html

California Renewables Portfolio Standard Program, 2584, Cong. (2014).

Capehart, B. (2014). Microturbines. Retrieved December 7, 2014, from http://www.wbdg.org/resources/microturbines.php

Capstone Microturbine Corporation. (2009). Product specification (Technical Publication No. 460051 Rev D.). Chatsworth, CA: Capstone.

Capstone Microturbine Corporation. (2010). Product catalog No. P0212 CAP115). Chatsworth, CA: Capstone Corporation.

Chisom, C., & Templeton, J. (2013). Analysis of Marine Corps renewable energy planning to meet installation energy security requirements. Monterey, California: Naval Postgraduate School.

Energy Information Administration (EIA). (2013a). 2001–present: Net generation by state by type of producer by energy source [Spreadsheet]. Retrieved August 11, 2013, from http://www.eia.gov/electricity/data/state

Energy.gov. (n.d.). Retrieved December 2, 2014, from http://energy.gov/oe/services/cybersecurity

EPA Clean Energy Calculator, Retrieved Dec 2, 1014 from http://www.epa.gov/cleanenergy/energy-resources/refs.html

ESTCP. (2012). ESTCP cost and performance report: Distributed power systems for sustainable energy (Technical Report No. EW-200939). Alexandria, VA: Environmental Security Technology Certification Program.

ESTCP. (2013). ESTCP cost and performance report: Smart microgrid energy management controls for improved energy efficiency and renewables integration at DoD installations (Technical Report No. EW-200937). Alexandria, VA: Environmental Security Technology Certification Program.

ESTCP. (2014). Microgrid enabled distributed energy solutions (MEDES) -fort bliss military reservation (Technical Report No. EW-201140). Alexandria, VA: Environmental Security Technology Certification Program.

Feldman, D., Barbose, G., Margolis, R., James, T., Weaver, S., Darghouth, N., et al. (2014). Photovoltaic system pricing trends No. NREL/PR-6A20-62558). Berkley, CA: SunShot, U.S. Department of Energy.

Giraldez, J., Booth, S., Anderson, K., & Massey, K. (2012). Valuing energy security: Customer damage function methodology and case studies at DoD installations (No. NREL/TP-7A30–55913). Golden, CO: National Renewable Energy Laboratory.

Goodrich, A., James, T., and Woodhouse, M. 2012. Residential, "Commercial, and Utility-Scale Photovoltaic System Prices in the United States: Current Drivers and Cost-Reduction Opportunities", NREL Technical Report, NRE/TP-6A20_53347.

Headquarters, United States Marine Corps (HQMC). (2011). The United States Marine Corps expeditionary energy strategy and implementation policy. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a541407.pdf

Headquarters, United States Marine Corps (HQMC). (2013). The United States Marine Corps installations energy strategy. Washington, DC: Marine Corps Expeditionary Energy Office & Installations and Logistics.

Klein, J., & Rhyne, I. (2014). Estimated Cost of New Renewable and Fossil Generation in California. Sacramento: California Energy Commission

Lazard's levelized cost of energy analysis version 8.0, (September 2014) , Lazard's Global Power, Energy & Infrastructure Group.

McAvoy, T. (2011). 10 Things You Didn't Know About Microturbines. Chicago, IL: New Loop Energy.

Morris, G., Abbey, C., Joos, G., & Marnay, C. (2011). A framework for the evaluation of the cost and benefits of microgrids (Technical Report No. LBNL-5025E). Berkley, CA: Ernest Orlando Lawrence Berkeley National Laboratory.

National Defense Budget Estimates for FY 2015 (April 2014). Office of the Under Secretary of Defense (Comptroller).

National Research Energy Laboratory. (2014, September 22). Photovoltaic System Pricing Trends; Historical, Recent, and Near-Term Projections 2014 Edition

National Energy Research Laboratory. (2008). U.S. solar resource map NREL.

National Renewable Energy Laboratory. (2009, October 1). Power Purchase Agreement Checklist for State and Local Governments. Energy Analysis, 1-1.

National Renewable Energy Laboratory. (2014). Learning about renewable energy: Biomass energy basics. Retrieved December 7, 2014, from http://www.nrel.gov/learning/re_biomass.html

National Research Energy Laboratory. (2014). Wind farm calculator. Retrieved December 7, 2014, from http://www.energybc.ca/cache/wind2/www.nrel.gov/analysis/power_databook/calc_wind.html

OMB. Circular A-76, “Performance of Commercial Activities”, (May. 29, 2014).

OMB. Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs", Memorandum m-14-05, (Feb. 27, 2014).

Southern California Edison. (2014, February 7). Our Reliability Reports, Listed by County. Retrieved December 2, 2014, from https://www.sce.com/wps/portal/home/outage-center/reliability-reports/!ut/p/b0/04_Sj9CPykssy0xPLMnMz0vMAfGjzOK9PF0cDd1NjDwNLINMDRydgyxMDQPcDH1MjfULsh0VAYClcXE!/#/accordionGrp1-10

U.S. Department of Energy. (2014). Alternative fuels data center. Retrieved December 7, 2014, from http://www.afdc.energy.gov/fuels/emerging_biogas.html

U.S. Energy Information Administration. (n.d.). Natural Gas Industrial Price. Retrieved December 2, 2014, from http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PIN_DMcf_m.htm

U.S. Environmental Protection Agency. (2013). Environmental technology verification program. Retrieved December 7, 2014, from http://www.epa.gov/etv/

U.S. Environmental Protection Agency. (2014). Environmental technology verification (ETV) program case studies: Demonstrating program outcomes (Tech Report No. EPA/600/R-06/001). Cincinnati, OH: Office of Research and Development.

US Environmental Protection Agency. (2010). Landfill Gas Modeling. In LFG Energy Project Development Handbook (p. 7). Washington, DC: US Environmental Protection Agency.

Van Broekhoven, S. B. Judson, N. Nguyen, S. V. T. Ross, W. D. (18 June 2012). “Microgrid Study: Energy Security for DoD Installations”, (ESC-EN-HA-TR-2012-103). Lexington, Massachusetts: Massachusetts Institute of Technology.

Vestel, L. (2010, August 26). Wind Turbine Projects Run Into Resistance. Retrieved December 2, 2014, from http://www.nytimes.com/2010/08/27/business/energy-environment/27radar.html?_r=1&

Ye, Z., Walling, R., Miller, N., Du, P., & Nelson, K. (2005). Facility microgrids (Technical Report No. NREL/SR-560-38019). New York, NY: General Electric Global Research Center.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California